FINAL REPORT

POTENTIAL FAILURE MODE ANALYSIS
KOOTENAI DEVELOPMENT IMPOUNDMENT DAM

LINCOLN COUNTY, MONTANA

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ABBREVIATIONS

AF .... ACRE FOOT
CFS .... CUBIC FEET PER SECOND
HMR .... HYDROMETEORLOGICAL REPORT
PGA .... PEAK GROUND ACCELERATION
PFMA .... POTENTIAL FAILURE MODES ANALYSIS
PMF .... PROBABLE MAXIMUM FLOOD
PMP .... PROBABLE MAXIMUM PRECIPITATION

1.0 EXECUTIVE SUMMARY

The impoundment behind the Kootenai Development Impoundment Dam (KDID) is the mine tailings reservoir used in the processing of vermicuiite on the former Zonolite Mine near Libby, Montana. The impoundment has been dormant since 1990 when W.R. Grace, the owners of record, discontinued mining activities at the site. Changing conditions on the site have required that the dam's current condition be analyzed and the possible need for improvements or mitigation measures be addressed.

The Montana Potential Failure Mode Analysis (PFMA) process was selected for its group approach to identifying potential failure modes on the site. The PFMA process was conducted on the KDID by Billmayer & Hafferman Inc. (BHI) following the guidance, assistance and recommendation of Montana Dam Safety Program in order to indentify and prioritize future work projects on the site. The intent of the Montana PFMA process is a non-binding examination in that it is not to be a decision document, but rather a useful reference tool.

The PFMA for the KDID used a Core Team of individuals to conduct a systematic process to identify potential failure modes, list and examine them in a group setting, identify factors of the dam that make the failure mode more or less likely and categorize them in one of four categories based on available data. The KDID PFMA was conducted on May 25th and 26th, 2011 in Libby.

Work on the project site is on the US EPA Libby superfund site. Work on the site is hazardous to humans and requires significant planning to address the on site hazard, "Libby Amphibole Asbestos". Work projects conducted at the site must always consider environmental consequences to both human and nature before proceeding.

The PFMA was prompted by recent investigations of the embankment toe drains that revealed that the drains are failing internally and transporting embankment and drain material during seasonally high reservoir levels. Other significant issues include structural cracks in the principal spillway, a concrete box culvert.

The findings of this report reveal that the current, greatest vulnerability, with this embankment dam is the spillway structures. The principal spillway was found to be structurally stressed with longitudinal cracks in the floor and ceiling of the box culvert and it's susceptibility to plugging in storm events. The emergency spillway was noted as, "More likely to cause a breach", than function as a spillway. These structures led to flooding events that are the most likely initiating factors for a dam failure. Because of the asbestos release factor, the team recognized the impacts a dam breach or failure could have on the surrounding area. This was a significant influence in finding the principal and emergency spillways to be the greatest potential failure mode concern.

The Core Team found that the downstream construction technique, coupled with the high density embankment material has resulted in a more stable structure than most tailings dams of this type. The Core Team felt that the embankment is not subject to liquefaction from or by or seismic failure. The Core Team found that the greatest likelihood of seismic failure on this project may be the failure of the box culvert on the principal spillway. Seismic failure was identified as also having the potential to collapse any internal void in the dam resulting in the loss of structural integrity of the dam.

A significant finding by the Core Team was the rapid and dramatic elevation spikes in piezometer levels that occur seasonally. These elevation spikes are most likely increases in foundation pore pressure and not actual saturation of the embankment. Even though groundwater springs have been reported as existing in the foundation, the source of water was found to be most certainly Rainy Creek. Pressurizing of the foundation likely occurs when inflows become greater than the gravel alluvium can store or when the reservoir level increases to the point of providing a flow pathway. Pressurizing the foundation often results in artesian groundwater flow, or springs.

The Core Team also speculated that an old buried decant line may be open in or beneath the reservoir and when inflows exceed drain capacity, the reservoir rises allowing water to enter the decant line resulting in the pressure rises recorded by piezometer P2.

The Core Team unanimously agreed that the drain system at the toe of the dam is failing and will continue to fail over time. The team also agreed that the toe drains associated with the foundation are generally effective at decreasing embankment pore pressures for most of the year and the drainage system installed during construction of the dam is rather extensive when compared to similar tailing impoundment dams. The Core Team found that the foundation gravels are not vulnerable to scour during periods of high flow gradients and the high porosity of the gravels likely assures that little to no saturation of the embankment occurs under normal operating conditions.

The Core Team discussed rerouting Rainy Creek around the impoundment, as was the case during mining operations, as a corrective action. Because the greatest threat of failure at the impoundment occurs during flood conditions, diverting the creek flows may not adequately address all risks identified with the embankment dam. Bypassing the dam will likely still require corrective actions be taken on the dam itself.

In addition, the Core Team recognized that there is at present measurement and monitoring equipment that provides a sufficient surveillance system on site; but, there is a need to have real time access to on-site data.

This report and its attachments are intended to be a reference document for future decisions and work projects performed on the site. It provides areas of identified weakness and susceptibility to adverse operating conditions and or failure. Future data collection and monitoring of the site may identify additional failure modes or the need to revisit and revise existing failure modes identified during the PFMA process. The team agrees that the documents created as a part of this process are intended to be working documents that are subject to change as explorations are completed, questions are answered or remedial work is performed on the site.

2.0 INTRODUCTION

The impoundment behind the Kootenai Development Impoundment Dam (KDID) is the mine tailings reservoir used in the processing of vermicuiite on the former Zonolite Company mine near Libby, Montana. The impoundment has been dormant since 1990 when W.R. Grace, the owners of record, discontinued mining activities on the site. Changing site conditions have required that the condition of the dam be analyzed and the possible need for improvements, mitigation or remedial measures be addressed. The Potential Failure Mode Analysis (PFMA) process was selected for its group approach to identifying potential failure modes on the site that can be used to identify and prioritize future projects.

2.1 KDID PFMA

As part of the Federal Energy Regulatory Commission (FERC) Dam Safety Performance Monitoring Program in cooperation with a team of dam owners and independent consultants, the FERC developed guidance for carrying out a PFMA[1]. Those procedures, which include the use of a facilitator to guide the PFMA, have been used and tested by FEMA and have been adopted, in a modified form, by the Montana Dam Safety Program (MDSP). At the recommendation of MDSP the Montana PFMA process was adopted as the model to be conducted on the KDID. The PFMA process was conducted on the KDID by Billmayer & Hafferman Inc. (BHI) following the guidance, assistance and recommendation of MDSP in order to prioritize future work projects on the site.

The PFMA for the KDID used a Core Team of individuals to conduct a systematic process to identify potential failure modes, list and examine them in a group setting, identify factors of the dam that make the failure mode more or less likely and categorize them in one of four categories based on the available data. All available information, data and reports were prepared for and reviewed by the Core Team prior to the PFMA implementation. That data is referenced and contained within this report and the raw data is provided in a series of CD's in Appendix 2 to this report. The KDID PFMA was conducted on May 25th and 26th, 2011 in Libby. The process included an on-site visit to the KDID by the Core Team in a positive air pressure vehicle on May 25th. The PFMA was conducted at the main conference room of the Libby Branch of the Flathead Valley Community College on May 26th.

Information that was previously presented to the Core Team was used to develop and rank the failure modes by significance and is based on the group's combined professional opinion. Further the PFMA was used to potentially identify areas that require additional monitoring, surveillance or data collection in order to accurately assess the condition of the dam at a later date and reduce risks on the site.

The intent of the Montana PFMA process is a non-binding examination in that it is not to be a decision document, but rather a useful reference tool for everyone involved in the

[1] DSPMP/PFMA - Improving FERC's Dam Safety Program
http://www.ferc.gov/industries/hydropower/safety/guidelines/dspmp/facilitators.asp

safety of the KDID to utilize in making decisions on the project. The KDID PFMA is to be used as a tool when on-site modifications are contemplated and or prioritize areas where action may be best taken to reduce risks. The PFMA process is a supplement to traditional engineering analysis and not a replacement. [2]

The KDID PFMA process successfully identified failure modes or potential failure modes specific to the KDID dam. This PFMA report will now be used to conduct a fiill assessment of the risks before remedial actions are carried out. The KDID PFMA was also used to develop a strategy for surveillance on the stmcture and identified new monitoring instrumentation to help reduce risk.

2.2 KDID PROJECT INFORMATION

The KDID is located in Lincoln County, Montana 5.3 miles east of Libby on Rainy Creek just northeast of Montana Highway 37. The site is more specifically located in the northwest quarter of Section 22, and die southwest quarter of Section 15, Township 31 North, Range 30 West, Principal Meridian, Montana and is located on Rainy Creek, a tributary of Kootenai River. The dam and reservoir are owned by the Kootenai Development Company, c/o Remedium Group, Inc. of Memphis, Tennessee, and was originally used as an impoimdment for mine tailings by Zonolite Inc. and W.R. Grace & Co. The dam is a 135 ft. high earthen tailings impoundment dam. The toe of the dam is near elevation 2796 ft. MSL, the crest is at 2926 ft. MSL and the maximum tailing elevation adjacent to the upstream slope of the dam is near 2891 ft. MSL, showing approximately 95 ft. of tailings upstream of the dam. The starter dam was constmcted in 1971 with additions (or lifts) made in 1973, 1975, 1976, and 1980. There is no inlet or outlet control stmctures for the dam and inflows and outflows are uncontrolled.

Access to the dam is obtained off of Montana Highway 37, 5.3 miles east of Libby at the USFS #401 Rainy Creek road. The dam is located 2.6 miles north of the highway and the USFS road is the only controlled road access to the KDID. This road is located in the inundation area below the dam and could be flooded in the event of a dam failure or flood event.[3]

The KDID is located entirely on the US EPA Libby Superfimd site. The EPA has been working in Libby since 1999 when an Emergency Response Team was sent to investigate local concem and news articles about asbestos-contaminated vermicuiite[4]. The KDID is the former mine tailings impoundment dam that was left on the mine site when the project was decommissioned in 1990. The embankment and tailings impoundment is composed of mine tailings that contain substantial amounts of Libby Amphibole asbestos. Work in and around and access to the dam is severely restricted to protect the health and safety of persons accessing the site. Entry into the restricted zone requires special training, aimual certification in hazardous waste operations and emergency response (HAZWOPER) and appropriate personal protective equipment (PPE) that has been fit-

[2] ibid FERC's Dam Safety Program

[3] KDID 5-Year Operational Permit Renewal Report, BHI, 3/25/2009

[4] http://www.epa.gov/libby/background and http://www.epa.eov/reaion8/superfund/libbv Libby Asbestos

tested and EPA approved. Only 40-hour HAZWOPER certified individuals in PPE are allowed onsite outside of a pressurized vehicle. Decontamination facilities for personnel and mobile equipment must also be available and persomel must be trained in the use of decontamination procedures and decontamination must be carried out when exiting the site.

2.3 KDID HISTORY

Commercial vermicuiite mining on the project site was initiated in 1923 by the Zonolite Company. The material was dry milled until 1954 when the first wet mill was installed in response to dust levels onsite. The original dam is presumed to have been installed at this time. In 1956 the U.S. Department of Health informed the Montana Health Department that it was estimated that 10% of the Libby ore was asbestos. In 1961, a Montana State Board of Health Study showed extremely high and substantial concentrations of asbestos dust in the Libby Mine. W.R. Grace acquired the Mine fiom the Zonolite Company in 1963 and in 1966 the Montana Board of Health noted reductions in dust levels relative to past inspections but requested further engineering improvements. In response, W.R. Grace further researched wet mill technology and began constmction of a 50 foot tall starter dam in 1971. The starter dam was raised in lifts in 1973, 1975, 1976 and 1980 reaching a total stmctural height of 135 feet. The original plans were to eventually reach a total height of 200 feet but due to decreasing product demand the mine ended production in 1990. Closure plans and meetings with regulatory officials were carried into 1993 when additional piezometers and the principal and emergency spillways were installed on the site and re-vegetation efforts were carried out.

During closure plans consultants to W.R. Grace, Shaffer and Associates, determined that the most effective routing of water in the basin was through the reservoir. Previously, Rainy Creek was diverted in a culvert around the reservoir and only Fleetwood Creek flows were routed through the reservoir. It was determined that the flood routing capacity of the reservoir using a designed stmcture was the most feasible and safest method for routing Rainy Creek through the area.[5]

The principal and emergency spillways were installed by W.R. Grace in 1993 and the dam has largely been undisturbed since. There were anecdotal reports that were lacking documentation of site inspections conducted from 1993 to 1999. In September of 1999 Michael Ray, P.E., of Ray Engineering completed a dam safety inspection and subsequent report and then conducted periodic inspections until October of 2006. In June of 2007 Billmayer & Hafferman, Inc. (BHI) took over inspections on the project. Routine Owners Inspections (ROI) has been performed by BHI and Chapman Constmction on a monthly basis since June of 2007. BHI has completed ROI monthly reports documenting site conditions as required by the MDSP dam safety operations permit since 2007. Special reports and investigations completed have included but are not limited to the MDSP 5-year Operational Permit Renewal, Annual Emergency Action Plan Updates, toe

[5] Appendix 3 Reference 3: Engineering Analysis ofiFlood Routing Altematives for the W.R. Grace Vermicuiite Tailings Impoundment Libby, Montana, Shaffer and Associates, Bozeman, Montana, Bruce K. Parker and Thomas J. Hudson

drain investigation reports, and a hydrologic and hydraulic stream bypass feasibility study.

In addition to monthly inspections, work projects on site and subsequent reports included crack repair and maintenance on the box culvert and open chute principal spillway, installation of flumes and weirs and the development of a hydrography program, repair of drain outlets at the toe of the dam, video inspection of all the drains from the downstream ends and video inspection of the piezometers on the embankment.

BHI has determined that, to date, the dam has performed satisfactorily with no major catastrophic issues. The focus of the PFMA were those issues that BHI detennine were either showing signs of fiiture poor perfonnance or presented performance that was not fully understood due to lack of sufficient historic documentation. BHI had determined that the drains, while showing signs of capacity loss, are currently capable of routing water past the embankment without spillway flows for 80% of the year. But, video inspection of the drains has revealed that deterioration of the drain pipes is occurring and embankment materials are entering the pipes at various locations and are being transported out of the drains. Further, the performance of the drains under conditions of full reservoir head has not been tested and is therefore unknown. BHI found that the principal spillway, though stmcturally stressed, has not notably changed since BHI inspections began. The earthen emergency spillway is constructed over the right abutment and has no effective outlet channel other than down the downstream face of the embankment. However, the earthen spillway has never been tested and the principal spillways have yet to be fully tested and the performance of these stmctures as designed has been questioned.

2.4 KDID PFMA CORE TEAM MEMBERS

The potential Core Team members were identified and recommended by BHI and selected by the owner, the Remedium Group. The Core Team was selected to be first and foremost experienced in earthen embankment dam constmction and analysis. The second selection criteria was one or more fields of expertise in mine tailings dams, geology, hydrology, hydraulics and dam safety. The Core Team members and their key experience specific to the KDID PFMA were as follows;

Kurt Haffennan, P.E., BHI, KDID Engineer of Record, HAZWOPER certified, Hydraulics, Hydrography, Earthen Embankment Dams, Dam Safety, Owners Representative.
Deb Miller, P.E., Miller Geotechnical Consultants, Inc., Earthen Embankment Dams, Geotechnical, Facilitator.
Jay Thom, P.E., DOWL HKM, Montana Earthen Embankment Dams, Hydraulics, Hydrology, Dam Safety.
James Obermeyer, P.E., MWH Americas, Inc., Mine Tailings, Geotechnical, Earthen Embankment Dams.
Michelle Lemieux, P.E., Montana DNRC Dam Safety, State Regulator, Earthen Embankment Dams, Hydrology, Hydraulics.

Dan Nelson, Billmayer & Hafferman, Inc., Survey Technician, HAZWOPER certified. Report Writer, PFMA organization.

2.5 PFMA OBSERVERS

PFMA observers were selected or asked to attend based on a particular site specific knowledge, because they had requested to attend, or were required to be present.

Bob Medler, Remedium Group, Owners Representative, site specific knowledge.
Laurence Siroky, P.E., Montana DNRC Dam Safety, State Regulator, dam safety experience, site specific knowledge.
Christina Progess, US EPA, Required Observer.
Mike Chapman, Chapman Constmction, Owners Dam Tender, Local Contractor, Site specific knowledge.
Vic White, Lincoln County Emergency Response, Required Observer.

3.0 DAM DESCRIPTION

3.1 EMBANKMENT AND RESERVOIR HISTORY

The embankment dam was constmcted in five (5) phases from 1971 to 1980 in a downstream progression. The starter dam began as a 50 foot tall impoundment dam and through the constmction phases now measures 135 feet in height. It was designed as a tailings impoamdment dam to retain fine tails produced in the vermicuiite mining process.

During mine production, the reservoir level was controlled by the use of decant towers with log weirs that maintained the level and prevented fine tails from being transported below the impoundment. Rainy Creek flows were rerouted to bypass the impoundment and only Fleetwood creek continuously flowed into the reservoir. As part of mine closure, the decant towers were removed and the Rainy Creek bypass was dismantled. Once the Rainy Creek bypass was decommissioned the waters of Rainy Creek were passed drough the impoundment. There is no stmcture to control inflows or an outlet stmcture to control the reservoir level. The reservoir level is generally controlled by the elevation of the inlet channel to the principal spillway. Although it was originally assumed that the majority of the annual volume of water would pass over the spillway, it has come to pass that 80% of the total annual volume of water passes through the tailings and routes out through the toe drain system[6]. Only the remaining 20% of the annual volume of water passes through the principal spillway and bypasses the drains.

3.2 EMBANKMENT COMPOSITION

"The embankment dam is composed primarily of old coarse mill tails that were stockpiled on the site and mixed with gravel obtained from the old mill pond below the dam. The material was placed in 6 inch lifts and compacted to 95% of the maximum

[6] BHI Toe Drain Inspection Report, April 6, 2010

modified proctor lab density. Soils density tests taken during constmction showed dry densities of 144 to 149 pounds per cubic foot."[7]

3.3 EMBANKMENT TOE DRAINS

Water is primarily routed through the impounded tailings and through the embankment and its foundation by a series of 13 drains located at the base of the dam and discharging at the downstream toe. As stated above, 80% of the total annual volume of water passes through the tailings and routes through the toe drain system while the remaining 20% of the seasonally high flows typically are passed by the principal spillway for a short time during the year. To date, the highest recorded spillway flows have resulted in less than 1 foot of head at the entrance channel to the box culvert.

BHI has labeled the toe drains from left to right looking downstream; Drain 6, a 14-inch O.D. steel pipe exiting in the middle of the embankment toe, is the main drain carrying the highest volume of water through the embankment. The remaining twelve drains are a combination of 6-inch, 8-inch and 10-inch unreinforced concrete pipe and corrngated metal pipes.[8]

A primary concem with the toe drains is that as drains fail over time it will cause water that flows through the tailings to be reduced causing in the principal spillway channel to flow more frequently and, unless other constmction alters the current design, will become the primary means of routing water through the reservoir and past the embankment. The issue of routing water through the spillway rather than through the drains has become both a stmctural and an environmental concem. The box culvert has a centerline crack in both the ceiling and the floor and the long term stmctural stability has been questioned, in particular if the embankment material on top of the culvert was to become saturated in an extreme storm event. Environmental concems regarding latent asbestos becoming suspended in water and transported through the tailings reservoir and over the spillway have been raised and are currently being monitored[9]. Water that is routed through the tailings impoundment, the embankment and the toe drains is reported to be relatively free of suspended asbestos particles and it appears that the mine tailings and embankment serve as an effective asbestos filter[10]. Water that flows over the spillway contains high levels of asbestos and littie to no settlement or filtering of the asbestos contained in the inflow occurs.[11]

Another current concem is that failure of the drains may lead to uncontrolled seepage on the downstream face of the dam. Uncontrolled seepage on the downstream face of the embankment will result in destabilization of the foundation at the toe of the embankment. Seepage on the face of the embankment will flow through unconsolidated tailings to the

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[7] Appendix 3 Reference 1
[8] ibid
[9] Pers. Cons. via telephone John Garr, MWH, June 2009 John D. Garr, P.G. Supervising Hydrogeologist, MWH,
[10] ibid
[11] ibid

toe and will carry substantial amounts of asbestos into Rainy Creek and fiirther downstream.

3.4 SITE GEOLOGY

The right abutment slope is underlain by glacial outwash and tlll that is likely a lateral moraine to an approximate elevation of 2890. This glacial outwash ranges from a few feet to nearly 40 feet in thickness. Near the top of the abutment, the alluvium is made up of nearly horizontally bedded silty sandy gravels overlaid with approximately 6 feet of thinly laminated fme silt.[12]

The left abutment is blanketed by a thin mantle of slope debris and remnants of a lateral moraine near the base of the slope. Near an elevation of 2830, there is a renmant of an outwash terrace capped by 4 feet of highly permeable, relatively clean sand and gravel.[13]

The valley floor consists mainly of glacial outwash and alluvium. The glacial outwash is mainly fine to coarse grained gravels with 10% or less of fme sands and silts. The gravels contain zones of very high porosity and permeability. A 1-inch to 2-inch thick layer of nearly white silt overlies the glacial outwash and is covered by unconsolidated alluvium made of up soft silt up to a depth of 6 feet. This alluvium silt may or may not have been removed during the phased constmction of the embankment.[14]. It is suspected that the glacial outwash at the valley floor is a major conduit for water that flows through the tailings and into the foundation under the embankment dam.

3.5 KEY DAM FEATURES

Date Constmcted 1971-1980

Slope of Upstream Face of Dam (Horizontal to Vertical) 2:1

Slope of Downstream Face of Dam (Horizontal to Vertical) 2:1

Dam Height Measured from the Downstream Toe to the Crest: .... 135 feet

Dam Crest Width: .... 40 feet

Dam Width at Base: .... 400 feet

Length of Dam Crest .... 1,100 feet

Max Reservoir Capacity to the Crest of the Dam: .... 1,219 AF

Reservoir Capacity at the Crest of the Earthen Emergency Spillway .... .937 AF

Earthen Emergency Spillway Capacity at Crest of Dam .... 1,129 CFS

Principal Spillway Capacity at Crest of Dam .... 765 CFS

Elevation at die Crest of the Dam (NAVD 29): .... 2927.5 feet

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[12] Appendix 3 Reference 4
[13] ibid

Principal Spillway Invert Elevation .... 2900 ft.

Elevation of the Invert of the Principal Spillway Entrance Channel .... 2903 ft

Normal Reservoir Capacity Measured to the Invert of the Principal Spillway Entrance Channel at elevation 2903: ....23 AF

Upstream Dam Height Measured from the Principal Spillway to the Crest: ....26 feet

Elevation of the Invert of the Earthen Emergency Spillway .... 2922 ft.

Water Depth Measured from the invert of the Emergency Spillway to the crest ....4.0 feet

3.6 DAM **HYDROLOGY** (Reference 2 and 3)

Available Freeboard: .... 20.6 feet on the 100-year event; 0.75 feet on the 0.50 PMF

Reservoir Surface Area: ....760 acres

Maximum Storage Capacity: .... 3,620 AF

Dam Hazard Classification: ....High

Storage Capacity to Crest of Dam: ....1,302 AF

Principal spillway capacity: ....744 CFS

Emergency spillway capacity: ....1,114 CFS

Design flood routing...0.5 PMF

Storm Event Analysis:

10-year 24 hour storm = 2.4 inches of precipitation...

.... Peak inflow estimate = 107 CFS at 15.5 hours

....Total nmoff = 74 AF

100-year 24 hour storm = 3.4 inches of precipitation ....

....Total runoff = 245 AF

.... Peak inflow estimate = 460 CFS at 14.8 hours

.... Peak outflow estimate = 243 CFS (20.6 ft. freeboard)

PMF (6 hour Summer Thunderstorm) ....

.... PMP = 10.7 inches (HMR 43 – Summer Thunderstorm)

.... PMF peak inflow estimate = 11,676 CFS at 5.0 hours

....Total runoff = 4,612 AF

.... ½ PMF peak inflow estimate = 5838 CFS

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[14] ibid

.... ½ PMF outflow estimate = 1171 CFS (0.75 ft. freeboard)

PMF (3 day Rain on Snow Event) ....

.... PMP = 13.9 inches (HMR 43 – Rain on Snow Event)

.... PMF peak inflow estimate = 3,704 CFS at 30.5 hours

.... ½ PMF peak inflow estimate = 1852 CFS

....Dam Routing Capacity = 0.53 PMF (Rain on Snow Event)

4.0 PFMA PROCESS

The following information generally follows the FERC PFMA and Montana PFMA reporting procedures using generally recognized headings and descriptions. The majority of the topics and data were taken verbatim from the flip charts by the PFMA facilitator Deb Miller, from review of the meeting video by Dan Nelson provided in Appendix 2, and from the meeting notes of Dan Nelson and Kurt Hafferman. The PFMA report followed the review time line and editing guidelines of the FERC PFMA and Montana PFMA process.

The information was edited for clarity and to correct spelling or to add cross references from the notes but was not changed in content or order or priority. No new or significant additional information was added to the KDID PFMA following the meeting and prior to the publishing of this report.

4.1 MAJOR FINDINGS AND UNDERSTANDINGS

Below is a summary of the major findings and understandings gained for the KDID as a result of the Potential Failure Modes Analysis (PFMA) process. The list below is the result of comments by the participants at the close of the PFMA workshop and represents the discussions and characteristics of the dam that were unexpected or significant to various participants in the operation and stability of the dam.

4.1.1 GENERAL FINDINGS

(1) The consensus of the PFMA meeting is that flood events are the highest concern. For static /seismic loading conditions, the dam would be expected to perform satisfactory.
(2) Data needs and the PFM's identified may need to be re-evaluated/visited after new data is collected or rehabilitation is done on the project.
(3) Asbestos has been found in all the water in the basin – drain flows, spillway flows, standing water in the reservoir and inflow into the reservoir. Asbestos is filtered in the drain flow but not in the spillway flows.
(4) The severity of environmental issues associated with the site is impressive.

(5) The core team was a diverse group on this PFMA (owner, engineer, contractor, EPA). They were very synergetic in evaluating potential failure modes and consequences.
(6) Incorrect or less than optimal designs can have major effects on the dam's safety.
(7) It was surprising to find, after group discussion, that the high foundation pore pressures did not lead to identification of slope stability failure modes.
(8) A greater understanding of the importance of documentation on projects and the need for written records was significant. This was highlighted with respect to as-built records of constmction in particular. On this project there are many written references to documents that are not available.
(9) It was surprising to find that bore logs for the PM piezometers were not on file. This goes along with some gaps in available information for this project, especially some of the more recent data.
(10) Composition of the foundation does not appear to be well understood and that is surprising.
(11) The environmental consequences associated with this dam are different from standard dam safety consequences and need to be evaluated independently.
(12) A possible need exists to establish adequate design criteria for environmental consequences of PFM's. Current Montana Dam safety design standards are intended for water retaining stmctures and do not take environmental consequences into consideration.
(13) Better DNRC/EPA interaction should be utilized and clarified in the future and the EPA wants to be proactive on this project and needs more discussion.
(14) It was surprising that the pathway for water under the dam was preferred in tailings dams at the time of constmction. This method of constmction is much different than water retaining dams.
(15) There was an interesting discussion on the decant lines, and the possibility that they could be associated with some of the PFM's evaluated.
(16) There may be more than one decant line in the embankment.
(17) There was discussion of isolating and channeling Rainy Creek and Fleetwood Creek above the dam on the west side of the tailings pond. For environmental purposes the system would need to provide onsite containment and treatment before routing the water to the Kootenai River.
(18) The vuhierability of the dam in non-extreme weather events is greater than expected.

4.1.2 NORMAL OPPERATIONS KEY FINDINGS

(19) The embankment appears to be unsaturated (group consensus). The jumps in piezometer levels are assumed to actually indicate a spike in pore pressure in the confined, pervious foundation and do not represent an actual rise in the phreatic water level within the dam.
(20) The concept that a sinkhole could develop on this project and the likely failure modes allowing it to happen were enlightening and will be more carefnlly watched in the future.
(21) The possibility of sinkholes or cavities developing inside the embankment without observable signs is conceming on this dam.

(22) The foundation pressures appear to rise with a small reservoir level increase as demonstrated by the piezometer P2's 30 foot rise without a significant increase in drain flows. A direct connection between the reservoir and foundation or drain system appears to exist.

4.1.3 FLOOD CONDITIONS KEY FINDINGS

(23) The many issues associated with the spillway and box culverts are surprising.
(24) Reservoir attenuation on flooding needs to be better understood to better evaluate risks and the spillways.
(25) Catastrophic failures of the dam are most associated with severe flooding events. Stability has resulted from settlement and consolidation of the tailings over a long dormant period. This stmcture is less likely to have a "flow" failure that could happen in an active tailings impoundment (the classic Italy failure) and the volume of tailings involved would probably be less than that for an active tailings impoundment.
(26) The principal spillway is stmcturally inadequate and a serious threat to the dam during a flood event.
(27) The bypass conduit used to bypass flows around the reservoir was dismantled during project abandonment. Rebuilding the bypass conduit is an option, however reducing inflows to the reservoir does not have much effect on dam safety failure modes, as the presence of water on the tailings during a non flood event is not a big concem.
(28) Flood events are the big concem and the bypass conduit would be irrelevant during a moderate, significant or major flood event.

4.1.4 EARTHQUAKE LOADING KEY FINDINGS

(29) Seismic failures are a low concem for this dam because of its constmction and the apparent dense nature the foundation material.

4.1.5 DRAINS KEY FINDINGS

(30) The embankment dam is actually in good shape overall. Group discussions reveal that it is actually strong and stable. However, the deteriorated drain pipes may be piping embankment material into the drain pipes and could be creating voids inside the embankment that are not visible and such defects could result in development of serious dam performance issues.
(31) A strong link may exist between the risk and consequences associated with high reservoir levels and problems with the drains. Performance of the drains is unknown when the reservoir exceeds historic recorded levels.
(32) Drain 6 seems to be connected in some way to a water source and increased pressure and flow beyond other toe drains. It deserves attention to leam more about source and flow path. A video should be made of the entire lengtii of Drain 6.
(33) The drains are failing and they will continue to fail with time.
(34) The drains may have been damaged during constmction rather than from slow piping of support material or another failure mechanism.

(35) The toe drains associated to the foundation are still effective in draining embankment pore pressures for most of the year. That could change in the future.
(36) Although the condition of the drains is bad, they appear to do a good job of keeping the phreatic surface in the embankment dovm.
(37) The drains have a different design then what is typical for water retaining dams. The drains seem to be designed to drain the foundation and possibly the tailings as well.
(38) Although piping of embankment materials into drains is a possibility, it is not identified as a dire situation requiring immediate action on the part of the owner, as was originally considered by the regulatory agency prior to the PFMA. A variety of other factors contribute to the condition of the drains and continued monitoring may be an acceptable approach.

4.1.6 KEY FINDINGS OF CONSEQUENCES

(39) Flows over the emergency spillway are more likely to lead to a breach than to allow it to safely fimction as a spillway.
(40) Failure of the dam would likely result in a downstream release of only a portion of the impounded tailings, but the distance of the flow downstream could be significant.
(41) Environmental damage resulting from failure of the dam would be significant and the potential for loss of life should not be mled out.

5.0 POTENTIAL FAILURE MODES

For each of the potential failure modes identified, a failure mode is briefly described and the factors that make the failure mode more likely (adverse factors) or less likely (positive factors) to occur are listed following the failure mode description. In addition, any specifically identified potential actions for risk reduction for each potential failure mode are provided as well.

Potential Failure Mode Categories:

The failure modes were placed into one of four categories as follows:

- Category I – Highlighted Potential Failure Modes: Those potential failure modes of greatest significance considering need for awareness, potential for occurrence, magnitude of consequence and likelihood of adverse response (physical possibility is evident, fundamental flaw or weakness is identified and conditions and events leading to failure seemed reasonable and credible) are highlighted.

- Category II – Potential Failure Modes Considered but not Highlighted: These are judged to be of lesser significance and likelihood than Category I failure modes. Note that even though these potential failure modes are considered less significant than Category I they are all also described and included with reasons for and against the occurrence of the potential failure mode. The reason for the lesser significance is noted and summarized in the documentation report or notes.

- Category III – More Information or Analyses are Needed in order to Classify: These potential failure modes to some degree lacked information to allow a confident judgment of significance and thus a dam safety investigative action or analyses can be recommended. Because action is required before resolution, the need for this action may also be highlighted.

- Category IV – Potential Failure Mode Ruled Out: Potential failure modes may be ruled out because the physical possibility does not exist, information came to light which eliminated the concem that had generated the development of the potential failure mode, or the potential failure mode is clearly so remote as to be non-credible or not reasonable to postulate.

Potential failure modes identified by the PFMA team are presented below. Given the potentially severe adverse environmental consequences associated with release of tailing materials from this facility, the core team chose to assign separate failure modes categories for environmental and dam safety consequences. A failure mode may have mixed categories assigned, depending on the specific conditions associated with the failure. For example, several failure modes were identified that were not highlighted for safety considerations, but were highlighted under the environmental category because there was a perceived likelihood for substantial release of tailings or embankment material without stmctural failure of the dam.

Failure Mode Identification:

The failure modes below are identified according to the initiating factor and the order in which they were presented by the group. This identification system allows an immediate identification of the type of event required to cause the failure mode. Table 1 below shows the prefix identification meaning. In addition some failure ID's are followed by an 'a' or 'b' suffix. This was done to indicate a failure mode that had differing consequences based on the site conditions and variables that could be present at the time the failure mode occurred (i.e. flood condition and no flood condition).

TABLE 1: FAILURE MODE IDENTIFICATION

Failure Mode Prefix	Description
S	Occurs under normal (Static) dam conditions
E	Failure Mode initiated by and earthquake or seismic event
H	Failure Mode initiated by hydraulic (Flood) event

5.1 CATEGORY I – HIGHLIGHTED POTENTIAL FAILURE MODES

S2a. Progressive internal erosion of compacted tailings dam material under non-flooding conditions, caused by cyclic (seasonal) pressurization and depressurization of the dam foundation accompanied by high volumes of under seepage, which gradually erodes and transports tailing material at the foundation contact and into open drain pipes, which leads to formation of a void or multiple voids inside the dam. These voids enlarge over time leading to backward erosion migration into the dam opening pathways for seepage, possibly along old decant pipes, ultimately resulting in a direct hydraulic connection with the reservoir and rapid erosion along the preferential seepage paths and interconnected erosion features leading to breach of the dam and release of loose, saturated tailings..

(Safety Category I – Environmental Category I)

Failure Mode Description: Under nonnal seasonal fluctuations, pore pressures in the pervious dam foundation cyclically pressurize and then dissipate on drainage. The dam itself is believed to be unsaturated, well compacted and dense, and therefore relatively impervious compared to the foundation. Erosion and transport of the erodible silty-sand tailing embankment material develops under the cyclic pressure fluctuations at unprotected interfaces. The tailing materials are transported into either the coarse gravel foundation and/or into open or failed drain pipes causing voids to develop within the dam. Indications of these voids have been observed by video camera inspections. The voids become pathways for progressive scour, causing enlargement and collapse of the voids. Dam material that is eroded is progressively carried downstream through the open drain pipes by the normally high and seasonally very high volume of under seepage, leading to progressive enlargement of intemal voids in the dam. More than one subsidiary condition leading to failure was envisioned by the working group under these conditions, as follows:

(1) At some point, during a time when foundation pressures are seasonably high and substantial underseepage is occurring, the voids inside the dam become pressurized and hydraulic fractures develop in the surrounding dense, unsaturated tailing. The cracks emanate from the intemal pressurized void(s) to the downstream face of the dam. Flows from the pressurized voids through these hydro-fractures rapidly erode the non-cohesive embankment materials in the crack(s). Erosion progresses in combination with high volumes of underseepage and leads to slumping or slope failure on the downstream face of the dam, and release of potentially large volumes of tailings materials into the downstream environment; or

(2) The void(s) and hydro-fractures at the downstream face intersect with preferential flow paths along a buried decant pipe creating a direct hydraulic comection to the reservoir leading to rapidly accelerating erosion and release of large quantities of water and tailing; or

(3) The undetected void(s) may collapse - opening sinkhole features on either the upstream or downstream side of the dam. This condition may not lead to failure except under conditions when the reservoir levels are high and the sinkhole features create a shorter pathway for seepage and scour erosion leading to possible breach of the dam if the reservoir is sufficientiy close to the dam (see Failure Mode S2b).

Adverse Factors:

(1) Apparent intemal voids were observed in the video inspections of the toe drains.

(2) Drain pipes are failing.

(3) Drain pipes have the possibility to collapse after a void is formed.

(4) The non-cohesive embankment is vulnerable to erosion but it can support a void due to its density and unsaturated moisture levels.
(5) A progressively enlarging void will not be visible during routine owner's inspections.
(6) Hydraulic fracture from the void to the downstream face could rapidly erode the downstream embankment material.
(7) Hydraulic fracture could intersect with a drain or decant line, allowing a pathway for scour and erosion.
(8) No internal filter zones or filter diaphragms were installed within the dam to minimize sediment transport.
(9) Seasonal high pressures and flow rates are observed and may aggravate conditions.
(10) The seasonal high pressures and flows have been shown to transport material.
(11) Data indicates toe drain clogging is getting worse.

Positive Factors:
(1) Multiple paths exist for pressure release, preventing or mitigating high pressures within a void.
(2) Monthly inspections could observe the development of piping or voids by the appearance of sand piles at the toe of the dam.
(3) The non-cohesive embankment material may collapse on the void, limiting progression inside the embankment.
(4) The reservoir pool is typically 500 feet upstream from the embankment dam during normal conditions. The development of a sinkhole on the downstream face under these conditions would not be catastrophic.

Potential Actions for Risk Reduction (Potential Failure Mode S2a):
(1) None at this time.

Other Considerations (Potential Failure Mode S2a):
(1) None at this time.

S2b. Progressive internal erosion of tailing dam material under high reservoir levels or inflows after internal voids have formed in the dam leading to progression of piping erosion back to the reservoir and an eventual breach of the dam.
(Safety Category I – Environmental Category I)

Failure Mode Description: This failure mode description is identical to the description for potential failure mode S2a, regarding the formation of internal erosion features (voids) and hydro-fractures in the dam, but the pathway from the potential exit points at the downstream face of the dam to the reservoir is shortened due to elevated reservoir levels, and exit gradients are higher due to elevated foundation pressures. Under this failure mode scenario, the conditions leading to failure occur at a time when flooding is also occurring such that the reservoir water surface is much closer to the dam than under normal conditions. The slope instability and/or flows through erosion and sinkhole features breach the dam back into the elevated reservoir, releasing potentially large volumes of water and tailing materials into the downstream environment.

Adverse Factors:

(1) Apparent voids were observed in the video inspections of the toe drains.
(2) Drain pipes are failing.
(3) Drain pipes have the possibility to collapse after a void is formed.
(4) The non-cohesive embankment is vulnerable to erosion but it can support a void due to its density and unsaturated moisture levels.
(5) A progressively enlarging void will not be visible during routine owner's inspections.
(6) Hydraulic fracture from the void to the downstream face could rapidly erode the downstream embankment material.
(7) Hydraulic fracture could intersect with a drain or decant line, allowing a pathway for scour and erosion.
(8) No intemal filter zones or filter diaphragms were installed within the dam to monitor sediment transport.
(9) Seasonal high pressures and flows rates are observed and may aggravate conditions.
(10) Seasonal high pressures and flows have been shown to transport material.
(11) Data indicates toe drain clogging is getting worse.
(12) Sinkhole development under high reservoir conditions is more severe.
(13) Access to the site can be difficult during high flows, especially during winter and spring conditions.
(14) The system has not been tested under high reservoir levels. Records imply that the reservoir has never been more than about one foot above the principal spillway crest.
(15) Sinkhole development on the upstream face could open to the reservoir without a hydraulic fracture.
(16) Downstream interfaces between dam constmction phases may provide preferential pathways to a void.
(17) Under high reservoir conditions, the water level is at or near the upstream face of the embankment.

Positive Factors:

(1) Multiple paths exist for pressure release, preventing or mitigating high pressures within a void.
(2) Monthly inspections could observe the development of piping or voids by the appearance of sand piles at the toe of the dam.
(3) The non-cohesive embankment material may collapse on the void, limiting its progression inside the embankment.
(4) Monitoring frequency goes up during large inflow events.
(5) A weather station is located onsite and it is monitored. Good SNOWTEL data is also available.
(6) No steady state phreatic line is apparent within the embankment indicating it is not saturated but more piezometer information is needed to verify.

Potential Actions for Risk Reduction (Potential Failure Mode S2b):

(1) None at this time.

Other Considerations (Potential Failure Mode S2b):

(1) None at this time.

H3. Structural failure or deformation of the box culvert leads to concentrated seepage and backward erosion piping and scour at the structure/embankment interface, which enlarges to form a breach in the dam at the principal spillway.

(Safety Category I – Environmental Category I)

Failure Mode Description: Stmctural failure or partial collapse or deformation of the concrete box culvert occurs during a normal spring runoff event or a flood event when the spillway is flowing. This initiates concentrated seepage flows at the interface between the concrete and the embankment where the embankment materials are loosened or where a gap has been created between the concrete and the embankment. The concentrated seepage triggers backward erosion, piping and scour along the interface. Erosion progresses in the embankment at the principal spillway and leads to an overtopping breach of the dam. This results in scouring of the embankment at the left abutment and a release of tailings.

Adverse Factors:

(1) The channel to the inlet of the principal spillway creates a direct connection to the reservoir.
(2) No piping prevention elements (filters or seepage cutoffs) are apparent in the design of the box culvert.
(3) Stmctural distress is evident with longitudinal cracks in the floor and ceiling of the box culvert.
(4) The deformations of the crovm of the box culvert have likely created soil arching above the culvert, increasing the likelihood of piping at high flood reservoir levels.
(5) The box culvert goes from an outlet controlled state to an inlet controlled state at 175 CFS.
(6) If the embankment material above the culvert were to become saturated, it could relieve the arching stresses and collapse the box culvert.
(7) The embankment material is highly erodible.

Positive Factors:

(1) Some reservoir attenuation will limit flows into the box culvert.
(2) The box culvert is relatively high in the embankment.
(3) Pre-warning of a large storm would allow for implementation of the emergency action plan protecting life but the environmental consequences will be high.

Potential Actions for Risk Reduction (Potential Failure Mode H3):

(1) None at this time.

Other Considerations (Potential Failure Mode H3):

(1) None at this time.

H4. A large flood event engages the emergency spillway with all other dam systems functioning normally and sustained flood discharges over the partially unlined spillway erodes the downstream embankment and soil materials in the right downstream groin of the dam, which leads to head cutting back into the dam crest and causes a dam breach and release of tailings and flood water.
(Safety Category I – Environmental Category I)

Failure Mode Description: The emergency spillway is an earth-cut charmel located at the right abutment contact with the tailings dam fill. The spillway channel is lined with riprap in its approach section and across the crest of the dam. The downstream discharge section of the spillway is unlined such that any overflows will impinge onto a steep, unprotected slope at the margin of highly erodible tailings, fill and native glacial soil materials. A 0.50 PMF flood event (Reference 2) engages the emergency spillway with all other dam components fiinctioning normally, including the principal spillway and foundation drains. The flood overflows erode and scour the discharge area and results in head cutting that works its way back through the vuhierable embankment fill to the dam crest, resulting in a breach of the dam and a release of tailings and flood water.

Adverse Factors:
(1) Highly erodible material in the downstream discharge charmel.
(2) The discharge channel is steep.
(3) Flows will impinge on the embankment
(4) No concrete sill or grade control stmcture exists.
(5) There is a poor hydraulic configuration and it is questionable if the spillway will perform as designed.
(6) The principal spillway configuration is susceptible to plugging which could cause the emergency spillway to operate at a lesser flood than designed.

Positive Factors:
(1) The upstream and dam crest portion of the spillway channel is riprap lined with an 8" gravel bedding under the riprap.
(2) Glacial till in the right abutment contains boulders that may slow erosion but the percentage of boulders is unknovm.
(3) Pre-waming of a large storm would allow for implementation of the emergency action plan protecting life but the environmental consequences will be high.
(4) Sustained flows would be required to result in a breach failure.
(5) Reservoir attenuation is significant for the drainage basin.
(6) The channel dike on the left side of the channel will help slow the rate of head cutting into the dam.

Potential Actions for Risk Reduction (Potential Failure Mode H4):
(1) None at this time.

Other Considerations (Potential Failure Mode H4):
(1) None at this time.

E3. Earthquake triggers a collapse or deformation of the box culvert on the principal spillway which opens hydraulic pathways through loosened embankment soils or through gaps at the structure/embankment interface, and at times when the reservoir inflows are high and the spillway is flowing, results in piping and erosion along the structure; leading to a breach at the principal spillway.
(Safety Category I – Environmental Category I)

<u>Failure Mode Description</u>: This failure mode description is similar to Potential Failure Mode H3, except that the stmctural collapse is triggered by an earthquake. This condition leads to failure or tailings release only when the reservoir stage is high and the spillway is flowing. Therefore the failure mode progresses if the earthquake damage occurs during a runoff event when the spillway is flowing, or if the damage occurs at a time when the spillway is not flowing and the condition is either not recognized and corrected, or it is not corrected in time prior to subsequent runoff events. Stmctural failure or partial collapse or deformation of the concrete box culvert leads to concentrated seepage flows at the interface between the concrete and the embankment where the embankment materials are loosened or where a gap has been created between the concrete and the embankment. The concentrated seepage triggers piping and erosion along the interface. Erosion progresses in the embankment at the principal spillway contact and ultimately leads to a breach of the dam at the location of the spillway. This results in scouring of the embankment at the left abutment and a release of tailings.

<u>Adverse Factors</u>:
(1) The channel to the inlet of the principal spillway creates a direct comection to the reservoir.
(2) No piping prevention elements are apparent in the design of the box culvert.
(3) Stmctural distress is evident with longitudinal cracks in the floor and ceiling of the box culvert.
(4) The deformations of the crown of the box culvert has likely created soil arching above the culvert, increasing the likelihood of piping at high flood reservoir levels.
(5) The box culvert goes from an outlet controlled state to an inlet controlled state at 175 CFS.
(6) The embankment material is highly erodible.
(7) An earthquake is capable of leveling the tailings in the reservoir. The leveling could cause more water to reach the box culvert and accelerate erosion.
(8) Pre-waming of an earthquake is not common.

<u>Positive Factors</u>:
(1) Flooding conditions or seasonally high reservoir levels are needed to cause erosion or a breach of the dam. Under nonnal conditions, repairs could be made to the spillway.
(2) The box culvert is relatively high in the embankment.

<u>Potential Actions for Risk Reduction (Potential Failure Mode E3)</u>:
(1) None at this time.

Other Considerations (Potential Failure Mode E3):

(1) None at this time.

E4. Earthquake triggers settlement of the downstream embankment, blocking the exits of one or more drain pipes, triggering elevated pressures in the foundation and inside any voids that are present in the dam, which leads to high exit gradients and hydro-fracturing, which opens cracks or pathways for seepage under pressure, which exits at the downstream toe or face of the dam and initiates scour erosion or piping that progressively works its way back through tbe dam and tailing materials ultimately developing into a continuous, hydraulically interconnected pathway to the reservoir which accelerates movement of tailing material along the erosion features and a release of tailing and water through the breach.

(Safety Category I – Environmental Category I)

Failure Mode Description: Earthquake vibrations cause settling of the dovmstream zone of the dam sufficient to block off one or more drain pipes. If blocking of drain 6 (the most productive drain) were to occur, a resultant large spike in pore pressure is expected. This results in suddenly elevated pore pressures in the dam foimdation and also in any voids that are present within the downstream zone of the dam. High exit gradients initiate erosion at the toe of the dam, and hydro-fracturing from pressurized intemal voids opens cracks and seepage pathways to the downstream face. High exit gradients initiate backward erosion piping along the hydro-fractured cracks. Erosion progresses backward along the crack fractures, widening the cracks and transporting tailing materials under high seepage flows and gradients. Backward piping erosion progresses upstream through the embankment and tailings until the bottom of the reservoir is breached by a piping feature.

Adverse Factors:

(1) Apparent voids were observed in the video inspections of the toe drains.
(2) Drain pipes are failing.
(3) Drain pipes have the possibility to collapse after a void is formed.
(4) The non-cohesive embankment is vulnerable to erosion but it can support a void due to its density and moisture levels.
(5) A progressively enlarging void will not be visible during routine owner's inspections.
(6) Hydraulic fracture from the void to the downstream face could rapidly erode the downstream embankment material.
(7) Hydraulic fracture could intersect with a drain or decant line, allowing a pathway for scour and erosion.
(8) High pressures and flow rates may aggravate conditions.
(9) Seasonal high pressures and flow have been shovm to transport material.
(10) Data indicates toe drain clogging is getting worse.
(11) Apparent voids were observed in the video inspections of the toe drains.
(12) Access to the site can be difficult during high flows, especially during winter and spring conditions.

(13) The system has not been tested under high reservoir levels. Records imply that the reservoir has never been more than about one foot above the principal spillway crest.
(14) Sinkhole development on the upstream face could open to the reservoir without a hydraulic fracture.
(15) Dovmstream interfaces between dam construction phases may provide preferential pathways to a void.
(16) Under high reservoir conditions, the water level is at or near the upstream face of the embankment.

Positive Factors:
(1) Multiple paths exist for pressure release, preventing or mitigating high pressures caused by drain 6 blockages.
(2) The non-cohesive embankment material may collapse on the void, limiting its progression inside the embankment.
(3) No steady state phreatic line is apparent within the embankment indicating it is not saturated but more piezometer information is needed to verify.

Potential Actions for Risk Reduction (Potential Failure Mode E4):
(1) None at this time.

Other Considerations (Potential Failure Mode E4):
(1) None at this time.

E5. Earthquake collapses a large, pressurized internal void in the dam, resulting in a sudden high spike in pressure and hydraulic fracturing of the dam and or sinkhole development that opens seepage and erosion pathways which, if not repaired before reservoir conditions are elevated, lead to seepage and erosion occurring through sinkhole and crack features, which erodes tailing materials and breaches the dam. (Safety Category I – Environmental Category I)

Failure Mode Description: Earthquake vibrations cause a pressurized intemal void within the dam to collapse. This results in a sudden spike in pressure around the void and hydraulic fracturing followed by sinkhole development on the embankment dam as the pressure dissipates. Under subsequent elevated reservoir conditions, seepage develops through the cracks and voids in the highly erodible dam materials, enlarging and expanding the cracks until there is a direct hydraulic connection back to the saturated tailings and reservoir and the erosion accelerates and breaches the dam.

Adverse Factors:
(1) Apparent voids were observed in the video inspections of the toe drains.
(2) Drain pipes are failing.
(3) Drain pipes have the possibility to collapse after a void is formed.
(4) The non-cohesive embankment is vulnerable to erosion but it can support a void due to its density and moisture levels.
(5) A progressively enlarging void will not be visible during routine owner's inspections.

(6) Hydraulic fracture from the void to the downstream face could rapidly erode the downstream embankment material.
(7) Hydraulic fracture could intersect with a drain or decant line, allowing a pathway for scour and erosion.
(8) No filter diaphragms were installed to minimize sediment transport.
(9) Seasonal high pressures and flow rates are observed and may aggravate conditions.
(10) Seasonal high pressures and flows have been shown to transport material.
(11) Data indicates toe drain clogging is getting worse.
(12) Sinkhole developments under high reservoir conditions are more severe.
(13) Access to the site can be difficult during high flows, especially during winter and spring conditions.
(14) The system has not been tested under high reservoir levels. Records imply that the reservoir has never been more than about one foot above the principal spillway crest.
(15) Sinkhole development on the upstream face could open to the reservoir without a hydraulic fracture.
(16) Downstream interfaces between dam construction phases may provide preferential pathways to a void.
(17) Under high reservoir conditions, the water level is at or near the upstream face of the embankment.

Positive Factors:
(1) Multiple paths exist for pressure release, preventing or mitigating high pressures within a void.
(2) Monthly inspections could observe the development of piping or voids by the appearance of sand piles at the toe of the dam.
(3) The non-cohesive embankment material may collapse on the void, limiting its progression inside the embankment.
(4) Monitoring frequency goes up during large inflow events.
(5) A weather station is located onsite and it is monitored. Good SNOWTEL data is also available.
(6) No steady state phreatic line is apparent within the embankment indicating it is not saturated but more piezometer information is needed to verify.

Potential Actions for Risk Reduction (Potential Failure Mode E5):
(1) None at this time.

Other Considerations (Potential Failure Mode E5):
(1) None at this time.

5.2 CATEGORY II – POTENTIAL FAILURE MODES CONSIDERED BUT NOT HIGHLIGHTED

S1a. Scour erosion initiates at the toe of the dam due to high foundation uplift pressures and high exit gradients under normal reservoir inflow conditions, which causes localized slumping at the toe, and as the erosion progresses backward along the foundation contact, loose materials at the toe are carried downstream by continuous high underseepage flows until the downstream slope progressively fails and breaches through the dam crest and upstream tailings, eventually releasing the loose, saturated tailings impounded behind the dam.

(Safety Category II – Environmental Category II)

Failure Mode Description: Scour erosion of the compacted tailing embankment initiates at the downstream toe of the dam during times when the foundation is under pressure and high volume underseepage is occurring. High volume underseepage occurs continuously and very high underseepage is observed annually during normal spring runoff and nonnal reservofr operations. High velocity flows progressively erode the embankment soils by direct scour along the dam/foundation contact. Progressive erosion continues in the non-cohesive embankment soils producing slumping and slope failure on the downstream slope. The slope failure progresses upstream as materials are continuously carried away by underseepage flows and the slope is repeatedly undercut by high toe uplift pressures and gradients, ultimately breaching back into the loose tailing behind the dam, which then flow out over the breach through the compacted dam section.

[Note: This potential failure mode, and the associated potential failure mode S1b were assigned to category II by the core team, primarily because it would initiate on the dovmstream toe of the dam in a visible area and would progress gradually (i.e., it would not be a sudden, catastrophic event). This was distinguished by the team from potential failure modes S2a and S2b which initiate from unseen intemal void features that the group felt could progress insidiously without being recognized under routine inspections to the point where sudden failure of the dam was possible.]

Adverse Factors:

(1) High inflow into the reservoir is a trigger that may initiate failure.
(2) The material is capable of bridging, sustaining an open "pipe".
(3) A high flow rate through the foundation as the toe area "opens up" could resuh in higher velocities and thus more scour potential.
(4) The embankment is composed of highly erodible material.
(5) The progressive failure of the drains aggravates a high toe gradient.
(6) The valley floor has a high gradient.
(7) Underseepage rates are historically high.

Positive Factors:

(1) The exit point may gain capacity as embankment material is transported away, reducing foundation pore pressure and thus slowing erosion for a time, naturally creating a foundation drain.
(2) Because this is a slow progressing failure mode, it would be visible as part of routine monitoring, allowing action to be taken.
(3) Based on piezometric data and field observations (lack of evident seepage on the dovmstream face of the dam), no phreatic surface in the embankment dam exists under nonnal conditions.
(4) Because of the size of the embankment, massive amounts of material have to be moved for failure to occur.

(5) Foundation gravels are not vulnerable to scour under high seepage gradients.

Potential Actions for Risk Reduction (Potential Failure Mode S1a):

(1) None at this time.

Other Considerations (Potential Failure Mode S1a):

(1) None at this time.

S1b. Breach initiated by scour erosion at the toe of the dam at a high reservoir level or inflow.

(Safety Category II – Environmental Category I)

Failure Mode Description: See description for Failure Mode S1a. The difference is that this failure mode occurs during unusually high reservoir inflows such that there is higher likelihood for substantially more tailings material to be scoured and transported leading to more adverse environmental consequences.

Adverse Factors:

(1) A high reservoir is a trigger that may initiate failure.
(2) The material is capable of bridging, sustaining an open "pipe".
(3) A high flow rate through the foundation as the toe area "opens up" could result in higher velocities and thus more scour potential.
(4) The embankment is composed of highly erodible material.
(5) The progressive failure of the drains aggravates a high toe gradient.
(6) The valley floor has a high gradient.
(7) Underseepage rates are historically high.
(8) The drain system has not been tested under high inflow conditions but large storm events have occurred in recent history. (Reference 5.)
(9) At higher reservoir levels, the water reaches the embankment and there is a shorter pathway to erode back to the reservoir.
(10) The box culvert could be vulnerable to failure; exacerbating this failure mode.
(11) Higher flows in the spring under the dam possibly increase foundation pore pressures and destabilize the toe.

Positive Factors:

(1) The exit point may gain capacity as embankment material is transported away, reducing foundation pore pressure and thus slowing erosion for a time naturally creating a foundation drain.
(2) Because this is a slow progressing failure mode, it would be visible as part of routine monitoring, allowing action to be taken.
(3) Based on piezometric data and field observations (lack of evident seepage on the downstream face of the dam), no phreatic surface in the embankment dam exists under normal conditions.
(4) Because of the size of the embankment, massive amounts of material have to be moved for failure to occur.
(5) Foundation gravels are not vulnerable to scour under high seepage gradients.
(6) A larger flood occurrence has a lower probability of occurrence.

Potential Actions for Risk Reduction (Potential Failure Mode S1b):

(1) None at this time.

Other Considerations (Potential Failure Mode S1b):

(1) None at this time.

S3.Failure and or plugging of Drain 6 (14" steel pipe)
(Safety Category II – Environmental Category II)

Failure Mode Description: Failure and or plugging of drain 6 (14" steel pipe). This is an important drain that connects to a "spring" that developed at the toe of the starter dam. Failure of the pipe due to corrosion, age, and or plugging blocks out large flows from the reservoir and elevates pore pressures in the dam foundation. This condition exacerbates the conditions leading to failure modes S1 and S2 and the progression to failure may be similar to those previously described for those potential failure modes. A distinction for this failure mode is that failure of Drain 6 could result in overwhehning flows in other drains and the foundation gravels leading to significantly elevated foundation pressures that build into the embankment causing slope instability due to the presence of a seepage face exiting on the downstream slope.

Adverse Factors:

(1) A gravel collar may not exist around the downstream end of the pipe as with other drains since it is not perforated.
(2) Steel is subject to long term corrosion.
(3) A high flow failure would mean water pressure has to be distributed to other drains.
(4) This failure could transfer pressures to areas of the embankment that have not previously seen them.
(5) Remediation and/or repairs for this failure would be difficult due to high flows.

Positive Factors:

(1) The pipe is currentiy intact well into the embankment dam.
(2) Steel pipe is stronger than concrete – it has not collapsed and has a long life.
(3) The pipe is believed to be connected to a manifold that could redistribute flows to other drains.
(4) This failure mode is similar to failure mode S1, it should be visible.

Potential Actions for Risk Reduction (Potential Failure Mode S3):

(1) None at this time.

Other Considerations (Potential Failure Mode S3):

(1) None at this time.

HI. **Plugging of the box culvert principal spillway due to debris bypassing the trash rack results in a rise of the reservoir level and engages the emergency spillway, followed by erosion and head cutting of the unlined lower emergency spillway discharge area, leading to breach of the dam at the emergency spillway.**

(Safety Category II – Environmental Category II)

Failure Mode Description: The trash rack for the principal spillway is a series of steel posts embedded across the spillway approach channel upstream from the box culvert entrance. Under large flow events, debris builds up on the posts causing flows and debris to bypass the trash rack and block the box culvert. The reservoir rises to the level of the emergency spillway and begins flowing and starts to erode the unprotected dovmstream groin area. Under sustained flows, the emergency spillway discharge area head cuts back toward the reservoir, ultimately breaching to the reservoir.

Adverse Factors:

(1) Once the debris barrier is dammed, debris may easily bypass the barrier and plug the box culvert.
(2) During flooding, debris is common.
(3) The watershed basin is heavily forested.
(4) Once the box culvert is plugged, no unplugging can be accomplished with equipment until the water level drops below the culvert because an excavator can not reach it from the crest of the embankment.
(5) The emergency spillway discharge area has a steep slope with highly erodible material.
(6) The emergency spillway has never been tested.
(7) A high and or sustained high reservoir can lead to stress of the under drain system.
(8) The lack of forest maintenance poses an increased risk to forest fires and increased debris in runoff.
(9) Hydrology data available for the site is vague.
(10) Raised reservoir levels result in increased pore pressure even with normal operation of the principal spillway. What happens when levels rise even higher?
(11) Ice damming is a concem because ice gets past trash track. The time of year is important as well as the level of flooding.
(12) No water level control stmcture exists to prepare for floods or icing.

Positive Factors:

(1) The trash rack should be effective to the top of the pipes.
(2) The large reservoir area can store lots of runoff
(3) The reservoir is "leaky". It will drain out in a few weeks to allow clearing of the box culvert on the principal spillway.
(4) The watershed is heavily forested.
(5) The upstream diversion on rainy creek will trap some debris.
(6) The road culvert will trap some of the debris.
(7) The emergency spillway is not in the middle of the dam.

Potential Actions for Risk Reduction (Potential Failure Mode H1):

(1) Consider doing additional flood routing scenarios with the principal spillway blocked to better understand the level of flooding that would engage flows in the emergency spillway.

Other Considerations (Potential Failure Mode H1):

(1) None at this time.

5.3 CATEGORY III – MORE INFORMATION OR ANALYSES ARE NEEDED IN ORDER TO CLASSIFY

S4. A decant line, hydraulically connected to the reservoir ruptures within the dam, causing a hydraulic fracture and or piping and erosion.

(Safety Category III – Environmental Category HI)

Failure Mode Description: Historic documents show two decant lines on the west side of the impoundment. One decant line is visibly plugged with concrete at its downstream end but may not be plugged at its upstream end, or may have ruptured at some point below the plugged upstream section, resulting in a direct hydraulic connection between the reservoir and the dam foundation gravels. This results in essentially full reservoir heads acting on the dam foundation when reservoir pools rise to the presumed elevation of the open upstream end of the decant pipe. High pressures in the foundation result in high seepage rates and scouring at the embankment toe, and/or hydraulic fracturing emanating from voids in the dam, as described under potential failure modes S1 and S2, respectively. This leads to piping and or erosion developing through the fractures or along the outside of the pipe. This condition would be exacerbated by flooding conditions.

Adverse Factors:

(1) Many case histories of tailings dam incidents can be associated with old decant lines.
(2) Even if the entire pond is evacuated, this may not result in dam failure but it could release a lot of tailings.
(3) The embankment dam is composed of highly erodible material.
(4) A high head potential exists on the decant lines.
(5) The positioning of the knovm decant lines in the dam make it difficult to repafr.
(6) Information is very limited on the abandonment techniques utilized on the decant lines.

Positive Factors:

(1) The long distance between the embankment dam and the reservoir under normal conditions (no flood and no seasonally high levels) gives a reduced potential for dam failure.
(2) Even if the entire pond is evacuated, dam failure may not result, but it could release a lot of tailings.

(3) The 10" decant line in the embankment is visibly sealed at the end and the valve is concreted.

<u>Potential Actions for Risk Reduction (Potential Failure Mode S4)</u>:
(1) None at this time

<u>Other Considerations (Potential Failure Mode S4)</u>:
(1) None at this time.

5.4 CATEGORY IV – POTENTIAL FAILURE MODE RULED OUT

H2. Blocking or hydraulic structural failure of the principal spillway chute (Safety Category IV – Environmental Category II)

<u>Failure Mode Description</u>: the chute on the principal spillway becomes blocked or has a hydraulic stmctural failure that causes water to flow outside of the stmcture.

This failure mode was mled out because the principal spillway chute is founded on bedrock and its orientation relative to the dam toe makes it highly unlikely that flows overtopping the spillway sidewalls would present a significant risk of erosion on the dam embankment sufficient to lead to a failure. Also the box culvert limits the magnitude of flows in the chamel even under higher reservoir elevations. The group consensus was to list the environmental category for this condition as Category II because the erosion and scour that could occur could release contaminated materials downstream.

E1. Slope failure of embankment dam due to a seismic event (Safety Category IV – Environmental Category IV)

<u>Failure Mode Description</u>: A seismic event at the embankment dam causes a slope failure of the embankment.

Although the dam is situated in a moderate seismic area, this potential failure mode was mled out based on the following observations:
(1) The embankment appears to be unsaturated under normal operating conditions, based on piezometric data.
(2) The embankment is well compacted and has a high density.
(3) The foundation is comprised of very coarse grained gravels and cobbles.
(4) Even if the tailings that are impounded behind the dam liquefy, they are restrained by the compacted, unsaturated embankment and have no place to go.
(5) The pseudo-static factors of safety for the downstream slope exceeded 1.1 for very conservative assumptions, including a high phreatic line in the dam which is not present and use of higher than predicted peak ground accelerations for the region compared to values recommended from recent studies for a nearby dam (Flower Creek Dam).

Some uncertainty exists about the conditions in the dam foundation because a key geotechnical report that is cited in the Phase I Inspection Report (Reference 1) - is missing from historic documents. However, based on the Phase I report, the group concluded that it is highly likely that the finer-grained alluvial materials were stripped from the ground surface in the dam foundation such that the embankment is founded on very coarse-grained glacial materials (sands, gravels and cobbles), which are not prone to significant strength reduction or liquefaction under the anticipated cyclic loading.

Potential Actions for Risk Reduction (Potential Failure Mode E1):

(1) None at this time.

Other Considerations (Potential Failure Mode E1):

(1) Additional information is not necessary for mled out failure modes, but data could be gained from explorations of other failure modes. (e.g. other piezometer borings).

E2. Foundation failure of the dam due to liquefaction in a seismic event.
(Safety Category **IV** – Environmental Category **IV**)

Failure Mode Description: A seismic event at the embankment dam causes liquefaction that result in foundation failure of the dam.

This failure mode was ruled out because the foundation materials are comprised of very coarse-grained and pervious glacial sands, gravels and cobbles. These materials are not prone to significant strength reduction or liquefaction under the anticipated cyclic loading.

Potential Actions for Risk Reduction (Potential Failure Mode E2):

(1) None at this time.

Other Considerations (Potential Failure Mode E2):

(1) Additional information is not necessary for ruled out failure modes, but data could be gained from explorations of other failure modes. (e.g. other piezometer borings).

5.5 POTENTIAL RISK REDUCTION ACTIONS

Discussions during the PFMA meeting included possible monitoring, surveillance and inspection suggestions that might be utilized in order to more accurately assess the likelihood and risk of failure modes associated with components of the dam. The items listed herein are not necessarily specific to any particular failure mode but could benefit the assessment of one or more failure modes identified during the PFMA process. Further, the recommendations below are not requirements to perform work, but were identified by the group as being capable of providing valuable infonnation and insight into components of the project or the identification of elements that may reveal a failure mode is occurring un-noticed at the site. The items below in each category are ranked by priority as determined by the core team.

Monitoring, Surveillance, and Corrective Action Suggestions from PFMA:

Site Improvements:

- Consider reducing/removing the reservoir by routing Rainy Creek around impoundment.
    a. Establish hydrologic criteria for bypass design to determine future dam concems due to flooding.
    b. Address stmctural adequacy and capacity of hydrologic elements for a large flood.
- Consider installing properly filtered, high capacity toe drain and downstream rock buttress.
    a. Determine seepage pattems and evaluate flow paths through dam.
    b. Provide stmctural/stability analysis to determine site limitations.
    c. Identify feasible drain improvement designs.

Decant Investigations and Closure:

- Consider additional video of 14" steel line (drain 6)
- Consider exploration program to determine if old decant lines are open to reservoir at higher pools (e.g. use geophysical surveys)
    a. If decant pipe intakes are located, try to inspect w/ camera, then properly seal.
- Explore Drain 6 further to determine (if possible) if it is an old decant pipe hydraulically connected that is "feeding" foundation pressures.
- Watch for changes in water level in Piezometer P2 and for changes in the flow rates at the drains when the small water pond along the west side of the impoundment becomes separated from the main water pond in the reservoir area.
    a. Consider a dye test in this small pond area to investigate whether the dye shows up in the drain flows and if so how long it takes for the dye to report to the drain(s).

Subsurface Investigations and Instrumentation:

- Added piezometer instrumentation - target zones of interest, especially foumdation and isolated in embankment zones. (e.g. to evaluate up/down gradients)
    a. Add piezometers in crest with bore logs and bore at least one hole into bedrock.
    b. Determine the validity of pore pressure assumptions in regards to piezometers and the phreatic water surface within the embankment.
    c. Determine geologic makeup of gravel foundation under the embankment and evaluate flow conditions.
- Consider field K- testing
- Perform a stability analysis for observed high pore pressure
    a. Associate seepage analysis to support evaluation of transient (changing) conditions.
    b. Evaluate possible drain repairs for compatibility with site conditions.
- Add telemetry instrumentation (real-time monitoring)

5.6 RANKING OF POTENTIAL FAILURE MODES

At the close of the PFMA session, the team created a likelihood and consequence graph of the failure modes identified throughout the process that assessed the current likelihood of occurrence versus the potential consequence of that failure mode by the team's professional judgment. This process is referred to as binning and highlights, based on these categories, the potential risk of each failure mode assuming no risk reduction measures are taken on the site. As this analysis is based on professional judgment and current available information, it is subject to change over time as further evaluation and investigations are conducted in the future. Also risk reduction or remedial work on the site has the potential to affect the ranking of one or more failure modes as detennined by the team.

Table 2 below shows the likelihood categories utilized for ranking and a description of the category. It is important to remember that the categorization of the failure modes is not based on a statistical approach, but rather professional opinion and judgment.

TABLE 2: LIKELIHOOD CATEGORIES

Category	Description
Not Likely	Failure mode is not impossible
Low	Failure mode is not likely
Moderate	Failure mode could happen
High	Failure mode is likely to occur
Expected	Failure mode will occur

Table 3 below shows the consequence categories utilized in the ranking of the failure modes. These are similar to the likelihood categories and reflect the amoımt of damage expected to be sustained if the failure mode were to occur. These categories also represent degrees of environmental consequence and risks downstream of the dam if it were to occur.

TABLE 3: CONSEQUENCE CATEGORIES

Category	Description
Extreme	Dam failure would result from failure mode
High	Major dam repairs would be required
Moderate	Some repairs would be needed
Low	The failure mode would be noticed but with littie to no damage
Negligible	You might not know the failure mode occurred or is occurring

Because of the environmental concems associated with tailings releases and asbestos laden water in the event of a breech, all failure modes were given both a safety category and an environmental effects category during failure mode discussions. In order to reflect the dual categorizations in this preliminary risk assessment, each category has been ranked with both a safety (S) rating and an environmental (E) rating. Table 4 below shows the results of the ranking session.

TABLE 4: LIKELIHOOD VS. CONSEQUENCE GRAPH

Consequence	Likelihood: Not Likely	Low	Moderate	High	Expected
Extreme		H4(S) H4(E)	H1(S) H1(E) H3(S) H3(E)		
High		S4(E)	S1b(E) S2b(E) S2b(S)		
Moderate		S3(E) E3(S)-some flow E4(s) E5(S)	S1b(S) S2a(S)		
Low		S1a(E) S1a(S) S3(S) S4(S)	S2a(E)		
Negligible		E3(S)-no flow E4(E) E5(E)			

E= environmental S= safety

In Table 4 above, risk increases to the upper right of the graph and decreases to the lower left as indicated by temperate colors in the graph. As can be seen, the greatest risks identified by this method are most associated with hydrologic related failure modes and more specifically, the spillways.

5.7 FAILURE MODES SUMMARY

Table 5 below summarizes the potential failure modes identified and evaluated by the team as part of the PFMA meeting and workshop.

TABLE 5: POTENTIAL FAILURE MODES SUMMARY

PFM	DESCRIPTION	LIKELIHOOD	CONSEQUENCE	ADVERSE FACTORS	POSITIVE FACTORS
				Category I – Highlighted Failure Modes	
S2a.	Progressive internal erosion of compacted tailings dam material under non-flooding conditions, caused by cyclic (seasonal) pressurization and depressurization of the dam foundation accompanied by high volumes of under seepage, which gradually erodes and transports tailing material at the foundation contact and into open drain pipes, which leads to formation of a void or multiple voids inside the dam. These voids enlarge over time leading to backward erosion migration into the dam opening pathways for seepage; possibly along old decant pipes, ultimately resulting in a direct hydraulic connection with the reservoir and rapid erosion along the preferential seepage paths and interconnected erosion features leading to breach of the dam and release of loose, saturated tailings. (Safety Category I – Environmental Category I)	Environmental – Moderate Safety - Moderate	Environmental – Low Safety - Low	(1) Apparent internal voids were observed in the video inspections of the toe drains. (2) Drain pipes are failing. (3) Drain pipes have the possibility to collapse after a void is formed. (4) The non-cohesive embankment is vulnerable to erosion but it can support a void due to its density and unsaturated moisture levels. (5) A progressively enlarging void will not be visible during routine owner's inspections. (6) Hydraulic fracture from the void to the downstream face could rapidly erode the downstream embankment material. (7) Hydraulic fracture could intersect with a drain or decant line, allowing a pathway for scour and erosion. (8) No internal filter zones or filter diaphragms were installed within the dam to minimize sediment transport. (9) Seasonal high pressures and flow rates are observed and may aggravate conditions. (10) The seasonal high pressures and flows have been shown to transport material. (11) Data indicates toe drain clogging is getting worse.	(1) Multiple paths exist for pressure release, preventing or mitigating high pressures within a void. (2) Monthly inspections could observe the development of piping or voids by the appearance of sand piles at the toe of the dam. (3) The non-cohesive embankment material may collapse on the void, limiting progression inside the embankment. (4) The reservoir pool is typically 500 feet upstream from the embankment dam during normal conditions. The development of a sinkhole on the downstream face under these conditions would not be catastrophic.
S2b.	Progressive internal erosion of tailing dam material under high reservoir levels or inflows after internal voids have formed in the dam leading to progression of piping erosion back to the reservoir and an eventual breach of the dam. (Safety Category I – Environmental Category I)	Environmental – Moderate Safety - Moderate	Environmental – High Safety - High	(1) Apparent voids were observed in the video inspections of the toe drains. (2) Drain pipes are failing. (3) Drain pipes have the possibility to collapse after a void is formed. (4) The non-cohesive embankment is vulnerable to erosion but it can support a void due to its density and unsaturated moisture levels. (5) A progressively enlarging void will not be visible during routine owner's inspections. (6) Hydraulic fracture from the void to the downstream face could rapidly erode the downstream embankment material. (7) Hydraulic fracture could intersect with a drain or decant line, allowing a pathway for scour and erosion. (8) No internal filter zones or filter diaphragms were installed within the dam to monitor sediment transport. (9) Seasonal high pressures and flows rates are observed and may aggravate conditions. (10) Seasonal high pressures and flows have been shown to transport material. (11) Data indicates toe drain clogging is getting worse. (12) Sinkhole development under high reservoir conditions is more severe. (13) Access to the site can be difficult during high flows, especially during winter and spring conditions. (14) The system has not been tested under high reservoir levels. Records imply that the reservoir has never been more than about one foot above the principal spillway crest. (15) Sinkhole development on the upstream face could open to the reservoir without a hydraulic fracture. (16) Downstream interfaces between dam construction phases may provide preferential pathways to a void. (17) Under high reservoir conditions, the water level is at or near the upstream face of the embankment.	(1) Multiple paths exist for pressure release, preventing or mitigating high pressures within a void. (2) Monthly inspections could observe the development of piping or voids by the appearance of sand piles at the toe of the dam. (3) The non-cohesive embankment material may collapse on the void, limiting its progression inside the embankment. (4) Monitoring frequency goes up during large inflow events. (5) A weather station is located onsite and it is monitored. Good SNOWTEL data is also available. (6) No steady state phreatic line is apparent within the embankment indicating it is not saturated but more piezometer information is needed to verify.

TABLE 5: POTENTIAL FAILURE MODES SUMMARY CONTINUED...

PFM	DESCRIPTION	LIKELIHOOD	CONSEQUENCE	ADVERSE FACTORS	POSITIVE FACTORS
H3.	Stmctural failure or deformation of the box culvert leads to concentrated seepage and backward erosion piping and scour at the stmcture/embankment interface, which enlarges to form a breach in the dam at the principal spillway. (Safety Category I – Environmental Category I)	Environmental – Moderate Safety – Moderate to High	Environmental – Extreme Safety - Extreme	(1) The channel to the inlet of the principal spillway creates a direct connection to the reservoir. (2) No piping prevention elements (filters or seepage cutoffs) are apparent in the design of the box culvert. (3) Stmctural distress is evident with longitudinal cracks in the floor and ceiling of the box culvert. (4) The deformations of the crown of the box culvert have likely created soil arching above the culvert, increasing the likelihood of piping at high flood reservoir levels. (5) The box culvert goes from an outlet controlled state to an inlet controlled state at 175 CFS. (6) If the embankment material above the culvert were to become saturated, it could relieve the arching stresses and collapse the box culvert. (7) The embankment material is highly erodible.	(1) Some reservoir attenuation will limit flows into the box culvert. (2) The box culvert is relatively high in the embankment. (3) Pre-waming of a large storm would allow for implementation of the emergency action plan protecting life but the environmental consequences will be high.
H4.	A large flood event engages the emergency spillway with all other dam systems fimctioning normally and sustained flood discharges over the partially unlimed spillway erodes the downstream embankment and soil materials in the right downstream groin of the dam, which leads to head cutting back into the dam crest and causes a dam breach and release of tailings and flood water. (Safety Category I – Environmental Category I)	Environmental – Low Safety – Low	Environmental – Extreme Safety – Extreme	(1) Highly erodible material in the downstream discharge channel. (2) The discharge channel is steep. (3) Flows will impinge on the embankment (4) No concrete sill or grade control stmcture exists. (5) There is a poor hydraulic configuration and it is questionable if the spillway will perfomi as designed. (6) The principal spillway configuration is susceptible to plugging which could cause the emergency spillway to operate at a lesser flood than designed.	(1) The upstream and dam crest portion of the spillway chaimel is riprap lined with an 8" gravel bedding under the riprap. (2) Glacial till in the right abutment contains boulders that may slow erosion but the percentage of boulders is unknown. (3) Pre-waming of a large storm would allow for implementation of the emergency action plan protecting life but the environmental consequences wiil be high. (4) Sustained flows would be required to result in a breach failure. (5) Reservoir attenuation is significant for the drainage basin. (6) The channel dike on the left side of the channel will help slow the rate of head cutting into the dam.
E3.	Earthquake triggers a collapse or deformation of the box culvert on the principal spillway which opens hydraulic pathways through loosened embankment soils or through gaps at the stmcture/embankment interface, and at times when the reservoir inflows are high and the spillway is flowing, resuhs in piping and erosion along the stmcture; leading to a breach at the principal spillway. (Safety Category I – Envtronmental Category I)	Environmental – Low Safety – Low	Environmental – Low Safety – Negligible to Moderate	(1) The channel to the inlet of the principal spillway creates a direct connection to the reservoir. (2) No piping prevention elements are apparent in the design of the box culvert. (3) Stmctural distress is evident with longitudinal cracks in the floor and ceiling of the box culvert. (4) The deformations of the crown of the box culvert has likely created soil arching above the culvert, increasing the likelihood of piping at high flood reservoir levels. (5) The box culvert goes from an outlet controlled state to an inlet controlled state at 175 CFS. (6) The embankment material is highly erodible. (7) An earthquake is capable of leveling the tailings in the reservoir. The leveling could cause more water to reach the box culvert and accelerate erosion. (8) Pre-waming of an earthquake is not common.	(1) Flooding conditions or seasonally high reservoir levels are needed to cause erosion or a breach of the dam. Under normal conditions, repairs could be made to the spillway. (2) The box culvert is relatively high in the embankment.

TABLE 5: POTENTIAL FAILURE MODES SUMMARY CONTINUED...

PFM	DESCRIPTION	LIKELIHOOD	CONSEQUENCE	ADVERSE FACTORS	POSITIVE FACTORS
E4.	Earthquake triggers settiement of the downstream embankment, blocking the exits of one or more drain pipes, triggering elevated pressures in the foundation and inside any voids that are present in the dam, which leads to high exit gradients and hydro-fracturing, which opens cracks or pathways for seepage under pressure, which exits at the downstream toe or face of the dam and initiates scour erosion or piping that progressively works its way back through the dam and tailing materials ultimately developing into a continuous, hydraulically interconnected pathway to the reservoir which accelerates movement of tailing material along the erosion features and a release of tailing and water through the breach. (Safety Category I – Envfronmental Category I)	Environmental – Low Safety – Low	Environmental – Negligible Safety – Moderate	(1) Apparent voids were observed in the video inspections of the toe drains. (2) Drain pipes are failing. (3) Drain pipes have the possibility to collapse after a void is formed. (4) The non-cohesive embankment is vulnerable to erosion but it can support a void due to its density and moisture levels. (5) A progressively enlarging void will not be visible during routine owner's inspections. (6) Hydraulic fiacture from the void to the downstream face could rapidly erode the downstream embankment material. (7) Hydraulic fracture could intersect with a drain or decant line, allowing a pathway for scour and erosion. (8) High pressures and flow rates may aggravate conditions. (9) Seasonal high pressures and flow have been shown to transport material. (10) Data indicates toe drain clogging is getting worse. (11) Apparent voids were observed in the video inspections of the toe drains. (12) Access to the site can be difficult during high flows, especially during winter and spring conditions. (13) The system has not been tested under high reservofr levels. Records imply that the reservofr has never been more than about one foot above the principal spillway crest. (14) Sinkhole development on the upstream face could open to the reservoir without a hydraulic fracture. (15) Downstream interfaces between dam constmction phases may provide preferential pathways to a void. (16) Under high reservotr conditions, the water level is at or near the upstream face of the embankment.	(1) Multiple paths exist for pressure release, preventing or mitigating high pressures caused by drain 6 blockages. (2) The non-cohesive embankment material may collapse on the void, limiting its progression inside the embankment. (3) No steady state phreatic line is apparent within the embankment indicating it is not saturated but more piezometer information is needed to verify.
E5.	Earthquake collapses a large, pressurized internal void in the dam, resulting in a sudden high spike in pressure and hydraulic fiacturing of the dam and or sinkhole development that opens seepage and erosion pathways which, if not repatred before reservofr conditions are elevated, lead to seepage and erosion occurring through sinkhole and crack features, which erodes tailing materials and breaches the dam. (Safety Category I – Envtrommental Category I)	Environmental – Low Safety – Low	EnvironmenE – Negligible Safety – Moderate	(1) Apparent voids were observed in the video inspections of the toe drains. (2) Drain pipes are failing. (3) Drain pipes have the possibility to collapse after a void is formed. (4) The non-cohesive embankment is vulnerable to erosion but it can support a void due to its density and moisture levels. (5) A progressively enlarging void will not be visible during routine owner's inspections. (6) Hydraulic fracture from the void to the downstream face could rapidly erode the downstream embankment material. (7) Hydraulic fracture could intersect with a drain or decant line, allowing a pathway for scour and erosion. (8) No filter diaphragms were installed to minimize sediment transport. (9) Seasonal high pressures and flow rates are observed and may aggravate conditions. (10) Seasonal high pressures and flows have been shown to transport material. (11) Data indicates toe drain clogging is getting worse. (12) Sinkhole development under high reservofr conditions is more severe. (13) Access to the site can be difficult during high flows, especially during winter and spring conditions. (14) The system has not been tested under high reservotr levels. Records imply that the reservoir has never been more than about one foot above the principal spillway crest. (15) Sinkhole development on the upstream face could open to the reservoir without a hydraulic fracture. (16) Downstream interfaces between dam constmction phases may provide preferential pathways to a void. (17) Under high reservoir conditions, the water level is at or near the upstream face of the embankment.	(1) Multiple paths exist for pressure release, preventing or mitigating high pressures within a void. (2) Monthly inspections could observe the development of piping or voids by the appearance of sand piles at the toe of the dam. (3) The non-cohesive embankment material may collapse on the void, limiting its progression inside the embankment. (4) Monitoring frequency goes up during large inflow events. (5) A weather station is located onsite and it is monitored. Good SNOWTEL data is also available. (6) No steady state phreatic line is apparent within the embankment indicating it is not saturated but more piezometer information is needed to verify.

TABLE 5: POTENTIAL FAILURE MODES SUMMARY CONTINUED...

PFM	DESCRIPTION	LIKELIHOOD	CONSEQUENCE	ADVERSE FACTORS	POSITIVE FACTORS
			Category II – Potential but not Highlighted Failure Modes		
S1a.	Scour erosion initiates at the toe of the dam due to high foundation uplift pressures and high exit gradients under normal reservoir inflow conditions, which causes localized slumping at the toe, and as the erosion progresses backward along the foundation contact, loose materials at the toe are carried downstream by continuous high underseepage flows until the downstream slope progressively fails and breaches through the dam crest and upstream tailings, eventually releasing the loose, saturated tailings impounded behind the dam. (Safety Category II – Environmental Category II)	Environmental – Low Safety – Low	Environmental – Low Safety – Low	(1) High inflow into the reservoir is a trigger that may initiate failure. (2) The material is capable of bridging, sustaining an open "pipe". (3) A high flow rate through the foundation as the toe area "opens up" could result in higher velocities and thus more scour potential. (4) The embankment is composed of highly erodible material. (5) The progressive failure of the drains aggravates a high toe gradient. (6) The valley floor has a high gradient. (7) Underseepage rates are historically high.	(1) The exit point may gain capacity as embankment material is transported away, reducing foundation pore pressure and thus slowing erosion for a time, naturally creating a foundation drain. (2) Because this is a slow progressing failure mode, it would be visible as part of routine monitoring, allowing action to be taken. (3) Based on piezometric data and field observations (lack of evident seepage on the downstream face of the dam), no phreatic surface in the embankment dam exists under nonnal conditions. (4) Because of the size of the embankment, massive amounts of material have to be moved for failure to occur. (5) Foundation gravels are not vulnerable to scour under high seepage gradients.
S1b.	Breach initiated by scour erosion at the toe of the dam at a high reservoir level or inflow. (Safety Categoιy II – Environmental Category I)	Environmental – Low to Moderate Safety – Moderate	Environmental – High to Extreme Safety – Moderate	(1) A high reservoir is a trigger that may initiate failure. (2) The material is capable of bridging, sustaining an open "pipe". (3) A high flow rate through the foundation as the toe area "opens up" could resuh in higher velocities and thus more scour potential. (4) The embankment is composed of highly erodible material. (5) The progressive failure of the drains aggravates a high toe gradient. (6) The valley floor has a high gradient. (7) Underseepage rates are historically high. (8) The drain system has not been tested under high inflow conditions but large storm events have occurred in recent history. (Reference 5.) (9) At higher reservoir levels, the water reaches the embankment and there is a shorter pathway to erode back to the reservoir. (10) The box culvert could be vulnerable to failure; exacerbating this failure mode. (11) Higher flows in the spring under the dam possibly increase foundation pore pressures and destabilize the toe.	(1) The exit point may gain capacity as embankment material is transported away, reducing foundation pore pressure and thus slowing erosion for a time naturally creating a foundation drain. (2) Because this is a slow progressing failure mode, it would be visible as part of routine monitoring, allowing action to be taken. (3) Based on piezometric data and field observations (lack of evident seepage on the downstream face of the dam), no phreatic surface in the embankment dam exists under nonnal conditions. (4) Because of the size of the embankment, massive amounts of material have to be moved for failure to occur. (5) Foundation gravels are not vulnerable to scour under high seepage gradients. (6) A larger flood occurrence has a lower probability of occurrence.
S3.	Failure and or plugging of Drain 6 (14" steel pipe) (Safety Category II – Environmental Category II)	Environmental – Low Safety – Low	Environmental – Moderate Safety – Low	(1) A gravel collar may not exist aroımd the downstream end of the pipe as with other drains since it is not perforated. (2) Steel is subject to long term corrosion. (3) A high flow failure would mean water pressure has to be distributed to other drains. (4) This failure could transfer pressures to areas of the embankment that have not previously seen them. (5) Remediation and/or repairs for this failure would be difficult due to high flows.	(1) The pipe is currently intact well into the embankment dam. (2) Steel pipe is stronger than concrete – it has not collapsed and has a long life. (3) The pipe is believed to be connected to a manifold that could redistribute flows to other drains. (4) This failure mode is similar to failure mode S1, it should be visible.

TABLE 5: POTENTIAL FAILURE MODES SUMMARY CONTINUED…

PFM	DESCRIPTION	LIKELIHOOD	CONSEQUENCE	ADVERSE FACTORS	POSITIVE FACTORS
HI.	Plugging of the box culvert principal spillway due to debris bypassing the trash rack results in a rise of the reservoir level and engages the emergency spillway, followed by erosion and head cutting of the unlined lower emergency spillway discharge area, leading to breach of the dam at the emergency spillway. (Safety Category II – Environmental Category II)	Environmental –Moderate Safety – Low to Moderate	Environmental – Extreme Safety – Extreme	(1) Once the debris barrier is dammed, debris may easily bypass the barrier and plug the box culvert. (2) During flooding, debris is common. (3) The watershed basin is heavily forested. (4) Once the box culvert is plugged, no unplugging can be accomplished with equipment until the water level drops below the culvert because an excavator can not reach it irom the crest of the embankment. (5) The emergency spillway discharge area has a steep slope with highly erodible material. (6) The emergency spillway has never been tested. (7) A high and or sustained high reservoir can lead to stress of the under drain system. (8) The lack of forest maintenance poses an increased risk to forest fires and increased debris in runoff. (9) Hydrology data available for the site is vague. (10) Raised reservoir levels result in increased pore pressure even with normal operation of the principal spillway. What happens when levels rise even higher? (11) Ice damming is a concem because ice gets past trash track. The time of year is important as well as the level of flooding. (12) No water level control stmcture exists to prepare for floods or icing.	(1) The trash rack should be effective to the top of the pipes. (2) The large reservoir area can store lots of runoff. (3) The reservoir is "leaky". It will drain out in a few weeks to allow clearing of the box culvert on the principal spillway. (4) The watershed is heavily forested. (5) The upstream diversion on rainy creek will trap some debris. (6) The road culvert will trap some of the debris. (7) The emergency spillway is not in the middle of the dam.
				Category III – More Information Needed to Classify	
S4.	A decant line, hydraulically connected to the reservoir mptures within the dam, causing a hydraulic iracture and or piping and erosion. (Safety Category III – Environmental Category III)	Environmental – Low Safety – Low	Environmental –High Safety – Low	(1) Many case histories of tailings dam incidents can be associated with old decant lines. (2) Even if the entire pond is evacuated, this may not result in dam failure but it could release a lot of tailings. (3) The embankment dam is composed of highly erodible material. (4) A high head potential exists on the decant lines. (5) The positioning of die known decant lines in the dam make it difficult to repair. (6) Information is very limited on the abandonment techniques utilized on the decant lines.	(1) The long distance between the embankment dam and the reservoir under normal conditions (no flood and no seasonally high levels) gives a reduced potential for dam failure. (2) Even if the entire pond is evacuated, dam failure may not result, but it could release a lot of tailings. (3) The 10" decant line in the embankment is visibly sealed at the end and the valve is concreted.
				Category IV – Failure Mode Ruled Out	
H2.	Blocking or hydraulic stmctural failure of the principal spillway chute (Safety Category IV – Environmental Category II)	N/A	N/A	This failure mode was mled out because the principal spillway chute is founded on bedrock and its orientation relative to the dam toe makes it highly unlikely that flows overtopping the spillway sidewalls would present a significant risk of erosion on the dam embankment sufficient to lead to a failure. Also the box culvert limits the magnitude of flows in the channel even under higher reservoir elevations. The group consensus was to list the environmental category for this condition as Category II because the erosion and scour that could occur could release contaminated materials downstream.	
E1.	Slope failure of embankment dam due to a seismic event (Safety Category IV – Environmental Category IV)	N/A	N/A	Although the dam is situated in a moderate seismic area, this potential failure mode was mled out based on the following observations: (1) The embankment appears to be unsaturated under normal operating conditions, based on piezometric data. (2) The embankment is well compacted and has a high density. (3) The foundation is comprised of very coarse grained gravels and cobbles. (4) Even if the tailings that are impounded behind the dam liquefy, they are restrained by the compacted, unsaturated embankment and have no place to go. (5) The pseudo-static factors of safety for the dovmstream slope exceeded 1.1 for very conservative assumptions, including a high phreatic line in the dam which is not present and use of higher than predicted peak ground accelerations for the region compared to values recommended irom recent studies for a nearby dam (Flower Creek Dam). Some uncertainty exists about the conditions in the dam foundation because a key geotechnical report that is cited in the Phase I Inspection Report (Reference 1) - is missing irom historic documents. However, based on the Phase 1 report, the group concluded that it is highly likely that the finer-grained alluvial materials were stripped irom the ground surface in the dam foundation such that the embankment is founded on very coarse-grained glacial materials (sands, gravels and cobbles), which are not prone to significant strength reduction or liquefaction under the anticipated cyclic loading.	
E2.	Foundation failure of the dam due to liquefaction in a seismic event. (Safety Category IV – Environmental Category IV)	N/A	N/A	This failure mode was mled out because the foundation materials are comprised of very coarse-grained and pervious glacial sands, gravels and cobbles. These materials are not prone to significant strength reduction or liquefaction under the anticipated cyclic loading.	

6.0 CONCLUSIONS

6.1 ENVIRONMENTAL CONSIDERATIONS

This project is located on a US EPA superfimd site. Access to the site is only attainable in a pressurized vehicle for viewing and Level C personal protection equipment (PPE) with a full face mask equipped with P100 filters to work on the site. Movement on the site is slow and hazardous due to asbestos and, as such, a quick response on this site is nearly impossible. Procedures carried out must be well planned and executed so work is completed in a safe and timely manner.

The embankment dam has been reported to provide filtration of asbestos in the water from the drainage basin above the Reservoir when compared to spillway flows. This is shown in water quality monitoring that takes place each year on the site. Because of the filtering of the tailings, drains and material in the embankment dam it is currently preferable that all flows go through the drain system. Measures to repair the drains or mitigate the effects of intemal piping related to the drain flows should be considered if this system is to be maintained as a filtering feature.

Because of the asbestos release factor, the team recognized the impacts a dam breach or failure could have on the surrounding area and this was a significant influence in finding the principal and emergency spillways to be the greatest potential failure mode concem. The core team also noted that current Montana Dam Safety standards do not take environmental issues into account and for this reason; current standards may not be adequate for this project and may need to be revisited. At the very least, environmental concems should be addressed with any design or work performed on the site. The environmental components of the site make it vulnerable in even non-extreme storm events.

6.2 SEISMIC STABILITY

The embankment dam was constructed in a dovmstream sequence instead of an upstream sequence as was typical of many of these types of dams. The Core Team found that this constmction technique, coupled with the embankment material that is a high density 95% compaction on a modified proctor and considering the gravel alluvium and glacial outwash foundation has resulted in a more stable stmcture than most tailings dams of this type. The dam has a crest width of 40 feet, reasonable upstream and downstream sloe angles and an approximate toe width of 400 feet. The base width of the dam provides for greater stability and resistance to erosion and scour failures of the dam. It is further surmised that the embankment is unsaturated and the measured rises in piezometers are actually the result of pore pressure changes and not saturation. These features combine to create a situation for which the Core Team felt that the embankment is not subject to liquefaction trom or by seismic failure.

Recent studies on the Flower Creek Dam south of Libby included research into the Libby area seismicity.[15] The data obtained also contains information that can be utilized on this project. The study concluded that for this project, the 1% probability of exceedance in 50 years (5000 year return period) results in a peak ground acceleration (PGA) of 0.1-0.2g and the 2% probability of exceedance in 50 years (2500 year return period) also results in a PGA of 0.1-0.2g. The HLA geotechnical report was run based on a PGA of 0.3g and resulted in a factor of safety of 1.1 with a high phreatic water surface within the embankment.[16] The Core Team found that the comparison of recent and HLA data further shows that there is little likelihood of seismic failure at the project site.

The Core Team found that the greatest likelihood of seismic failure on this project may be the failure of the box culvert on the principal spillway. But also found that unless the seismic event occurs during a flooding condition, dam breach or failure is not likely and repairs could be made to the structure. Another possible seismic failure identified is the possible collapse or separation of toe drains. Again the Core Team found that unless this event occurred during seasonally high water levels or a flooding event, this would not likely cause a breach of the dam, but could potentially cause problems later when high flows develop. This would cause an uneven rise in pore pressures and possibly accelerate scour if it were occurring. The spillway, if not collapsed, could handle normal flows in this event and provide time for repairs. The final seismic failure identified was the collapse of an internal void in the dam. Because there is a possibility that a void exists or could develop within in the dam, an earthquake has the possibility to collapse a void that has formed. This could lead to a sinkhole appearing on the dam or plugging of one or more drain pipes depending on the size of the void collapsed. If a sinkhole were to appear on the upstream face during seasonally high flows or flooding conditions, a breach is possible.

6.3 SPILLWAYS

The spillways constructed as part of this embankment dam were associated to dam failure or breach more than any other structures on the site. They were identified as having the highest likelihood of occurrence and the greatest consequence if failure were to occur. The principal spillway was identified as structurally unsound and the emergency spillway was stated as being more likely to cause a breach than function as a spillway. They were identified as the main point of vulnerability on the project. Because of the spillways, catastrophic failures of the dam are most associated with flooding events.

Dam failure as a result of debris or ice accumulation and ice damming causing plugging of the box culvert entrance was discussed by the Core Team in detail. The construction of the trash rack is such that it is subject to plugging by debris and ice accumulation. Because the basin above the reservoir is heavily treed and poorly maintained, it may cause an increased risk for forest fires. Following a fire the possibility of post fire debris accumulation during flooding, and/or fire debris in combination with ice jamming was considered the highest probability. This plugging

[15] Appendix 3 Reference 7
[16] Appendix 3 Reference 4

can result in a rapid and uncontrolled rise of the reservoir to a level above the trash rack that would allow debris to bypass the trash rack and potentially plug the box culvert entrance. If the box culvert entrance was to become plugged and the reservoir level was above or near the top of the concrete spillway channel, equipment would be unable to unplug the principal spillway because it is unreachable from the crest of the dam.

Plugging of the box culvert would result in a rise in reservoir levels that could lead to water flowing in the emergency spillway on the right abutment of the dam. The emergency spillway has never been used, but the downstream slope is very steep and composed of highly erodible, asbestos laden material. This makes it highly likely that if the emergency spillway is ever used, it could lead to a breach of the dam, or at the very least, significant erosion on the downstream face of the dam and a significant envfronmental disaster. If plugging or damming were to occur and reservoir levels did not rise to the emergency spillway, the drain system will eventually lower the reservoir to a level that repairs could be made to the box culvert.

The last major principal spillway issue addressed by the Core Team was the potential structural failure of or piping of material around the box culvert of the principal spillway. Because the reservoir water level is typically around 500 feet away from the embankment dam, the spillway channel is the only direct connection to the reservoir for most of the year. The box culvert already shows signs of structural distress with longitudinal cracks running the length of the floor and ceiling, making it more susceptible to long term failure. The Core Team also considered that there would be a catastrophic failure of the box culvert if the overburden on top of the culvert becomes saturated in a large flood event.

No headwall is apparent at the culvert entrance to cut off flows to the embankment or limit erosion at the entrance of the spillway. In addition, inflow water goes over the top of the box culvert at approximately 175 cfs; long before the maximum design flow of 765 cfs is reached. These factors, coupled with the fact that the embankment material is highly erodible, lead to a high possibility of box culvert failure that would result in significant scouring or potential breach on the left abutment and a release of asbestos laden tailings from the reservoir. However, collapse of the box culvert would likely permit some flow to continue to pass down the spillway and complete dam failure is unlikely to occur unless flooding conditions are present and high flows are sustained. Pre-waming of such an event is possible in the form of a large storm or runoff event predictions.

6.4 EMBANKMENT SATURATION AND PIEZOMETERS

A significant finding by the Core Team is the rapid and dramatic elevation spikes in piezometer levels that occur seasonally. The Core Team determined that the spikes in potentiometric water surface were most likely increases in foimdation pore pressure and not actual saturation of the embankment. The seasonal spikes that occur each spring were formerly assumed to be caused by saturation of the embankment due to toe drains reaching capacity. However, it must be stressed that a definite understanding of implications of the piezometer readings is not possible due to lack of information on the constmction details for the piezometers and a full understanding of the foundation materials. The Core Team speculated that there is a connection to either inflows or reservoir levels that causes the gravel zone in the foundation to go from a gravity flow to pressurized flow that causes the resultant spike in recorded potentiometric water levels. It was found to be possible that the alluvium or glacial materials upstream of the dam or at the reservoir rim have very permeable zones and provide for considerable flow through the foundation materials.

Even though groundwater springs are reported as existing in the foundation, the source of water was found to be most certainly Rainy Creek as measured inflows and outflows are consistent on the project. At the very least, the source must be below the Upper Rainy Creek and Fleetwood Creek Flume locations for the flow volumes to equalize. The alluvium under the foundation may slope to the surface near the Rainy Creek Inlet to the reservoir and act as a pathway for creek flows to utilize the gravels in the foundation. Pressurizing of the foundation likely occurs when inflows become greater than the gravel alluvium can take or when the reservoir level increases to the point of providing a pathway for flow.

The Core Team also speculated that an old buried decant line may be open in or beneath the reservoir and when inflows overcome drain capacity, the reservoir rises allowing water flow to enter and pressurize an old decant line and thus create the pressure rises recorded by piezometer P2. In all instances the Core Team found that high rise in pressure in piezometer P2 compared to a small reservoir level increase is significant and alarming.

The team concluded that the pressure source should be explored and recommended monitoring and surveillance of the pore pressures and associated seepage discharge including the installation of nested piezometers to monitor embankment saturation levels and real-time monitoring of piezometer and hydrography data to make better correlations to inflows, pore pressure, and reservoir levels.

6.5 TOE DRAINS

The Core Team unanimously agrees that the drain system at the toe of the dam is failing and will continue to fail with time. The team also agrees that the toe drains associated to the foundation are generally effective at draining embankment pore pressures for most of the year and the drainage system installed with this dam is rather extensive when compared to similar tailings impoumdment dams. Montana State Dam Safety pointed out that the drain system does not currentiy meet minimum standards because no filtering medium is installed. This standard however, applies to water retaining stmctures and the drains on this project may have been designed to drain the tailings. Also, as discussed, there is a possibility that at least one drain may be an old decant line.

Toe drain discussions led to five potential failure modes and were ranked below the failure modes related to the spillways. This is because a drain failure was not considered to be as catastrophic as spillway failure because dam failure was not as likely when compared to flooding failures and was not as large of a concem as originally expected although drain failure could lead to aggravation of spillway failure modes. The team believes that a strong link may exist between the risk and consequences associated with high reservoir levels and the toe drains. A significant point that was discussed is that the performance of the drains under high reservoir heads is unknovm because the maximum recorded flow depth through the principal spillway channel and concrete chute chamel has been less than 1 foot. It is possible that higher reservoir levels could result in significant erosion and piping of embankment materials into the drains, leading to significant damage.

The 2 foot diameter gravel collar that was found around the drain pipes were installed to act as a water transport in the event of drain failure, although the capacity of the gravel would likely be much less than the open drain pipes. The Core Team however, did decide that piping of the gravel collar material is physically occurring, as indicated by the video inspections, and would be aggravated by high pore pressures. Review of drain pipe videos shows sections of drains where the pipe appears to be gone and the soil is still somewhat holding the shape and indicates the embankment material can sustain voids. However, significant collapse of the embankment materials into the failed drain pipes is also apparent in the videos. The high erodibility of the embankment material makes it susceptible to piping and erosion. The progressive failure of the toe drains will likely cause increasing volumes of water to utilize the gravel collar for flow capacity increasing the potential for voids and piping to occur at higher rates.

Monitoring has shown that material transport is occurring at least seasonally during high pressure periods. The team discussed the fact that a void could be present within the embankment at this time and is going unnoticed. This can result in the eventual appearance of a sinkhole on the surface of the embankment dam. The team discussed that unless a sinkhole were to form on the upstream face of the dam during seasonally high flows or a flooding condition, failure of the dam is highly unlikely as the reservoir pool is typically more than 500 feet away from the embankment at most other times throughout the year.

As recommended during suggested monitoring, surveillance and corrective actions, a properly filtered high capacity toe drain with a downstream rock buttress could be installed to help mitigate erosion damage within the embankment and possibly ease rising intemal pore pressures. The team is of the opinion that it is a matter of time before the current condition of the embankment deteriorates and becomes a much larger problem. Mitigation measures should be explored and installed when and where appropriate.

6.6 DECANT LINES

The team carried out a detailed discussion on the decant lines and their abandonment. Decant lines have often been associated with tailings dam incidents and very little information is available on the decant tower and pipeline systems and how they were abandoned on this site. There is indication that the first decant line is likely completely filled with grout. The phase five decant line was to be abandoned the same way, but no documented confirmation is available.[17]

[17] Appendix 3 Reference 6

The first decant line outlet is visibly filled with concrete at the extreme dovmstream end but there is no proof of the entire line being filled.

The team also discussed the possibility that drain 6 could be an old undocumented decant line because its construction is different lrom any other toe drain installed on the project. Further, it closely resembles the constmction style of the first documented decant line. Therefore, drain 6 could be an original decant line installed as part of the original impoundment buih in 1954. Anecdotal information indicates Drain 6 may have been modified to allow interception of "groundwater spring" flows at the toe or foundation area of the embankment after an original tower was abandoned. Evidence can be seen in a video of Drain 6 that shows a cross-drain opening at 342 feet within the pipe and the pipe continuing beyond this point. The team speculated that this is possibly the "modified" groundwater spring drain entrance. The team concluded that drain 6 seems to be connected to a water source with increased pressure and flows greater than any other drain and deserves attention to leam more about the drain construction and its water source.

Monitoring and surveillance recommendations for the drains included a re-video of drain 6 to determine the extent of the pipe and to further explore the apparent cross druin inlet and determine if it is, in fact, an old decant line. Also, the team suggested the decant line inlets should be located. If found and the line can be unplugged, the decant lines should be videoed, features in the pipe should be located at measured distances and plans made to properly seal the inlet and grout fill within the entire downstream pipeline.

6.7 SINKHOLE DEVELOPMENT

The possibility of sinkhole development on this project because of the high erodibility of the embankment material was not previously considered. Discussion of the project and construction techniques relative to the compaction of the embankment that lead to a high density and unsaturated material makes the embankment capable of sustaining an open "pipe" within the embankment that would otherwise be unlikely. Sinkhole development will be more closely monitored in the future.

Seasonal material transport has been observed during periods of high pore pressure and provides for the possibility that a void or voids may already exist within the embankment or may develop in the future. The team pointed out that the massive amount of material that has to be moved to create a sinkhole or an eventual breach of the dam reduces the chance of this being a rapid failure mode, however expansion of the void(s) over time until the void eventually reaches tiie surface has certainly been knovm to occur on many projects.

The Core Team found that the foundation gravels are not vulnerable to scour under high seepage gradients and the high capacity of the gravels likely assures that little to no saturation of the embankment occurs under normal operating conditions. Monitoring, surveillance and corrective action suggestions included the installation of added piezometer instrumentation and exploratory core drilling to definitively determine foundation composition.

The Core Team surmised that solutions associated to prevention of material transport and sinkhole development will be the installation of a filtered high capacity toe drain and dovmstream rock buttress system. The Core Team also suggested that reducing inflows could extend the drain life and decrease sinkhole development progression by the possible rerouting of stream flows around the embankment.

6.8 EMBANKMENT FOUNDATION

A thorough and complete description of the foumdation materials and the constmction activities involving the foundation was not found after a review of the available technical data. The only available information indicates a 6 foot depth of alluvial material on top of glacial outwash as the foundation below the KDID embankment. References to reports from 1971 were cited that may address these data gaps, but are not on file with the DNRC, the owner, or any of the project engineers that were available.

The Core Team felt that the gravel may have been intended to act as a transport medium to get water to the drains as this is a standard mine tailings dam technique; get water to the drains. Review of documents indicate that later phases of dam constmction did involve stripping of the foundation but it is unclear, and is not documented to show whether or not this occurred during the initial construction phase. The gravel and/or the foundation may very well be the pathway for seepage under the dam and, when the foumdation material reaches capacity, the potentiometric water surface rises in piezometer P2.

The Core Team suggested that an attempt should be made to locate any past reports that reference foumdation composition. If reports can not be found that corroborates foundation composition, geologic explorations should be made to more adequately understand the foumdation under the embankment dam as well as cores through the embankment to better understand constmction techniques utilized.

6.9 IMPOUNDMENT BY-PASS

The Core Team discussed rerouting Rainy Creek around the impoundment, as occurred during mining operations, as a corrective action on the project. By rerouting flows the reservoir size could be reduced or possibly removed depending on the design. The team determined that depending on the hydrologic design capacity of the diversion system, flood routing may still need to occur in the reservoir and therefore flows through the drains and spillways will still occur. Because the greatest failure concems with the impoundment occur during flood conditions, a diversion of creek flows may not adequately address current risks with the embankment dam under these conditions. Therefore it is likely that rerouting creek flows will still result in necessary corrective actions on the dam itself. While a by-pass system may become the preferred altemative for creek routing in the future, the design must address any use of the impoundment for flood routing and include mitigation of the same possible failure modes associated with the continued use of the impoundment.

6.10 SURVEILLANCE

The Core Team recognized that there is measurement and monitoring equipment that provides a sufficient surveillance system on site but there is a need to have real time access to on site data. Real time data monitoring can be used to establish long term trends. Long term trends can be used to identify anomalies such as sudden or catastrophic changes in water surface, drain flows or outflows. Long term reliable monitoring data transmitted off site can be easily retrieved and safely stored. Current water level transducers on site can be wired to transmit real time water surface changes to a web site for real time water surface level monitoring.

The data collection discussed included geologic drilling to investigate the embankment and the foundation including core samples. By completing the bore hole with nested piezometers, transducers can be installed in the nested sections of the piezometers and, again, linked to real time data transmission. This data can be invaluable in monitoring and predicting drain flow and potentiometric water surface characteristics.

6.11 FUTURE PFMA REFERENCE COLLECTION

This report and its attachments are intended to be a reference document for future decisions and work projects performed on the site. It provides areas of identified weakness and susceptibility to adverse operating conditions and or failure. The recommendations listed herein are not requirements for work but rather suggestions to gain more information to make informed design decisions in the future.

Future data collection and monitoring on the site may identify more failure modes or the need to revisit and revise existing failure modes identified during the PFMA process. The team agrees that the documents created as a part of this process are intended to be working documents that are subject to change as explorations are completed, questions are answered or remedial work is performed on the site.

Future data may highlight failure modes that are not currently considered to be highly likely or carry a higher consequence to the environment or may change the stability and safety of the embankment dam. Future data may lessen the priority or eliminate potential failure modes.

This document should be kept current and up to date as more information is gathered and/or work is carried out that may change the vulnerabilities identified. It is recommended that the PFMA report be part of and appended to the Standard Operational Procedures for the KDID. This document should be reviewed annually or, at a minimum, as a part of the 5-year operational permit renewal process. The report should be preserved in its original condition for future use and a correction copy completed at each review interval.

7.0 APPENDED REFERENCES

Reference 1. Phase I Inspection Report – RAINY CREEK BASIN ZONOLITE TAILINGS DAM – September 1981. Morrison-Maierle Inc.

Reference 2. Rain on Snow PMF – Memo to Hardrock Mining Bureau - July 22, 1991. Shafer & Associates.

Reference 3. Engineering Analysis of Flood Routing Altematives - 1991-1992. Shafer & Associates.

Reference 4. Geotechnical Evaluation W.R. Grace Dam, Rainy Creek Montana – 1992. Harding Lawson and Associates.

Reference 5. W.R. Grace Memorandum –Libby Impoundment Dam – December 1, 1981. From J.W. Wolter to R.M. Vining.

Reference 6. Responses to W.R. Grace Closure Plan – First Review to Alan Stringer – May 22, 1992. Shafer & Associates.

Reference 7. Seizmic Hazard Assesment – Flower Creek Dam – DNRC Memo February 01, 2011. Montana DNRC.

6.0 CONCLUSIONS

6.1 ENVIRONMENTAL CONSIDERATIONS

This project is located on a US EPA superfund site. Access to the site is only attainable in a pressurized vehicle for viewing and Level C personal protection equipment (PPE) with a full face mask equipped with P100 filters to work on the site. Movement on the site is slow and hazardous due to asbestos and, as such, a quick response on this site is nearly impossible. Procedures carried out must be well planned and executed so work is completed in a safe and timely manner.

The embankment dam has been reported to provide filtration of asbestos in the water from the drainage basin above the Reservoir when compared to spillway flows. This is shovm in water quality monitoring that takes place each year on the site. Because of the filtering of the tailings, drains and material in the embankment dam it is currently preferable that all flows go through the drain system. Measures to repair the drains or mitigate the effects of intemal piping related to the drain flows should be considered if this system is to be maintained as a filtering feature.

Because of the asbestos release factor, the team recognized the impacts a dam breach or failure could have on the surrounding area and this was a significant influence in finding the principal and emergency spillways to be the greatest potential failure mode concem. The core team also noted that current Montana Dam Safety standards do not take environmental issues into account and for this reason; current standards may not be adequate for this project and may need to be revisited. At the very least, environmental concems should be addressed with any design or work performed on the site. The environmental components of the site make it vulnerable in even non-extreme storm events.

6.2 SEISMIC STABILITY

The embankment dam was constmcted in a downstream sequence instead of an upstream sequence as was typical of many of these types of dams. The Core Team found that this constmction technique, coupled with the embankment material that is a high density 95% compaction on a modified proctor and considering the gravel alluvium and glacial outwash foundation has resulted in a more stable structure than most tailings dams of this type. The dam has a crest width of 40 feet, reasonable upstream and dovmstream sloe angles and an approximate toe width of 400 feet. The base width of the dam provides for greater stability and resistance to erosion and scour failures of the dam. It is further surmised that the embankment is unsaturated and the measured rises in piezometers are actually the result of pore pressure changes and not saturation. These features combine to create a situation for which the Core Team felt that the embankment is not subject to liquefaction from or by seismic failure.

Recent studies on the Flower Creek Dam south of Libby included research into the Libby area seismicity.[15] The data obtained also contains information that can be utilized on this project. The study concluded that for this project, the 1% probability of exceedance in 50 years (5000 year return period) results in a peak ground acceleration (PGA) of 0.1-0.2g and the 2% probability of exceedance in 50 years (2500 year return period) also results in a PGA of 0.1-0.2g. The HLA geotechnical report was run based on a PGA of 0.3g and resulted in a factor of safety of 1.1 with a high phreatic water surface within the embankment.[16] The Core Team found that the comparison of recent and HLA data further shows that there is little likelihood of seismic failure at the project site.

The Core Team found that the greatest likelihood of seismic failure on this project may be the failure of the box culvert on the principal spillway. But also found that unless the seismic event occurs during a flooding condition, dam breach or failure is not likely and repairs could be made to the stmcture. Another possible seismic failure identified is the possible collapse or separation of toe drains. Again the Core Team found that unless this event occurred during seasonally high water levels or a flooding event, this would not likely cause a breach of the dam, but could potentially cause problems later when high flows develop. This would cause an uneven rise in pore pressures and possibly accelerate scour if it were occurring. The spillway, if not collapsed, could handle normal flows in this event and provide time for repairs. The final seismic failure identified was the collapse of an intemal void in the dam. Because there is a possibility that a void exists or could develop within in the dam, an earthquake has the possibility to collapse a void that has formed. This could lead to a sinkhole appearing on the dam or plugging of one or more drain pipes depending on the size of the void collapsed. If a sinkhole were to appear on the upstream face during seasonally high flows or flooding conditions, a breach is possible.

6,3 SPILLWAYS

The spillways constmcted as part of this embankment dam were associated to dam failure or breach more than any other stmctures on the site. They were identified as having the highest likelihood of occurrence and the greatest consequence if failure were to occur. The principal spillway was identified as stmcturally unsound and the emergency spillway was stated as being more likely to cause a breach than fimction as a spillway. They were identified as the main point of vulnerability on the project. Because of the spillways, catastrophic failures of the dam are most associated with flooding events.

Dam failure as a result of debris or ice accumulation and ice damming causing plugging of the box culvert entrance was discussed by the Core Team in detail. The constmction of the trash rack is such that it is subject to plugging by debris and ice accumulation. Because the basin above the reservoir is heavily treed and poorly maintained, it may cause an increased risk for forest fires. Following a fire the possibility of post fire debris accumulation during flooding, and/or fire debris in combination with ice jamming was considered the highest probability. This plugging

[15] Appendix 3 Reference 7
[16] Appendix 3 Reference 4

can result in a rapid and uncontrolled rise of the reservoir to a level above the trash rack that would allow debris to bypass the trash rack and potentially plug the box culvert entrance. If the box culvert entrance was to become plugged and the reservoir level was above or near the top of the concrete spillway channel, equipment would be unable to unplug the principal spillway because it is unreachable irom the crest of the dam.

Plugging of the box culvert would result in a rise in reservoir levels that could lead to water flowing in the emergency spillway on the right abutment of the dam. The emergency spillway has never been used, but the dovmstream slope is very steep and composed of highly erodible, asbestos laden material. This makes it highly likely that if the emergency spillway is ever used, it could lead to a breach of the dam, or at the very least, significant erosion on the downstream face of the dam and a significant environmental disaster. If plugging or damming were to occur and reservoir levels did not rise to the emergency spillway, the drain system will eventually lower the reservoir to a level that repairs could be made to the box culvert.

The last major principal spillway issue addressed by the Core Team was the potential structural failure of or piping of material around the box culvert of the principal spillway. Because the reservoir water level is typically around 500 feet away from the embankment dam, the spillway charmel is the only direct connection to the reservoir for most of the year. The box culvert already shows signs of structural distress with longitudinal cracks running the length of the floor and ceiling, making it more susceptible to long term failure. The Core Team also considered that there would be a catastrophic failure of the box culvert if the overburden on top of the culvert becomes saturated in a large flood event.

No headwall is apparent at the culvert entrance to cut off flows to the embankment or limit erosion at the entrance of the spillway. In addition, inflow water goes over the top of the box culvert at approximately 175 cfs; long before the maximum design flow of 765 cfs is reached. These factors, coupled with the fact that the embankment material is highly erodible, lead to a high possibility of box culvert failure that would result in significant scouring or potential breach on the left abutment and a release of asbestos laden tailings irom tiie reservoir. However, collapse of the box culvert would likely permit some flow to continue to pass down the spillway and complete dam failure is unlikely to occur unless flooding conditions are present and high flows are sustained. Pre-waming of such an event is possible in the form of a large storm or runoff event predictions.

6.4 EMBANKMENT SATURATION AND PIEZOMETERS

A significant finding by the Core Team is the rapid and dramatic elevation spikes in piezometer levels that occur seasonally. The Core Team determined that the spikes in potentiometric water surface were most likely increases in foundation pore pressure and not actual saturation of the embankment. The seasonal spikes that occur each spring were formerly assumed to be caused by saturution of the embankment due to toe drains reaching capacity. However, it must be stressed that a definite understanding of implications of the piezometer readings is not possible due to lack of information on the constmction details for the piezometers and a fiill imderstanding of the foundation materials. The Core Team speculated that there is a connection to either inflows or reservoir levels that causes the gravel zone in the foundation to go from a gravity flow to pressurized flow that causes the resultant spike in recorded potentiometric water levels. It was found to be possible that the alluvium or glacial materials upstream of the dam or at the reservoir rim have very permeable zones and provide for considerable flow through the foundation materials.

Even though groundwater springs are reported as existing in the foundation, the source of water was found to be most certainly Rainy Creek as measured inflows and outflows are consistent on the project. At the very least, the source must be below the Upper Rainy Creek and Fleetwood Creek Flume locations for the flow volumes to equalize. The alluvium under the foundation may slope to the surface near the Rainy Creek Inlet to the reservoir and act as a pathway for creek flows to utilize the gravels in the foundation. Pressurizing of the foundation likely occurs when inflows become greater than the gravel alluvium can take or when the reservoir level increases to the point of providing a pathway for flow.

The Core Team also speculated that an old buried decant line may be open in or beneath the reservoir and when inflows overcome drain capacity, the reservoir rises allowing water flow to enter and pressurize an old decant line and thus create the pressure rises recorded by piezometer P2. In all instances the Core Team found that high rise in pressure in piezometer P2 compared to a small reservoir level increase is significant and alarming.

The team concluded that the pressure source should be explored and recommended monitoring and surveillance of the pore pressures and associated seepage discharge including the installation of nested piezometers to monitor embankment saturation levels and real-time monitoring of piezometer and hydrography data to make better correlations to inflows, pore pressure, and reservoir levels.

6.5 TOE DRAINS

The Core Team unanimously agrees that the drain system at the toe of the dam is failing and will continue to fail with time. The team also agrees that the toe drains associated to the foundation are generally effective at draining embankment pore pressures for most of the year and the drainage system installed with this dam is rather extensive when compared to similar tailings impoundment dams. Montana State Dam Safety pointed out that the drain system does not currentiy meet minimum standards because no filtering medium is installed. This standard however, applies to water retaining stmctures and the drains on this project may have been designed to drain the tailings. Also, as discussed, there is a possibility that at least one drain may be an old decant line.

Toe drain discussions led to five potential failure modes and were ranked below the failure modes related to the spillways. This is because a drain failure was not considered to be as catastrophic as spillway failure because dam failure was not as likely when compared to flooding failures and was not as large of a concem as originally expected although drain failure could lead to aggravation of spillway failure modes. The team believes that a strong link may exist between the risk and consequences associated with high reservoir levels and the toe drains. A significant point that was discussed is that the perfonnance of the drains under high reservoir heads is unknovm because the maximum recorded flow depth through the principal spillway channel and concrete chute channel has been less than 1 foot. It is possible that higher reservoir levels could result in significant erosion and piping of embankment materials into the drains, leading to significant damage.

The 2 foot diameter gravel collar that was found around the drain pipes were installed to act as a water transport in the event of drain failure, although the capacity of the gravel would likely be much less than the open drain pipes. The Core Team however, did decide that piping of the gravel collar material is physically occurring, as indicated by the video inspections, and would be aggravated by high pore pressures. Review of drain pipe videos shows sections of drains where the pipe appears to be gone and the soil is still somewhat holding the shape and indicates tie embankment material can sustain voids. However, significant collapse of the embankment materials into the failed drain pipes is also apparent in the videos. The high erodibility of the embankment material makes it susceptible to piping and erosion. The progressive failure of the toe drains will likely cause increasing volumes of water to utilize the gravel collar for flow capacity increasing the potential for voids and piping to occur at higher rates.

Monitoring has shown that material transport is occurring at least seasonally during high pressure periods. The team discussed the fact that a void could be present within the embankment at this time and is going unnoticed. This can result in the eventual appearance of a sinkhole on the surface of the embankment dam. The team discussed that unless a sinkhole were to form on the upstream face of the dam during seasonally high flows or a flooding condition, failure of the dam is highly unlikely as the reservoir pool is typically more than 500 feet away from the embankment at most other times throughout the year.

As recommended during suggested monitoring, surveillance and corrective actions, a properly filtered high capacity toe drain with a downstream rock buttress could be installed to help mitigate erosion damage within the embankment and possibly ease rising intemal pore pressures. The team is of the opinion that it is a matter of time before the current condition of the embankment deteriorates and becomes a much larger problem. Mitigation measures should be explored and installed when and where appropriate.

6.6 DECANT LINES

The team carried out a detailed discussion on the decant lines and their abandonment. Decant lines have often been associated with tailings dam incidents and very little information is available on the decant tower and pipeline systems and how they were abandoned on this site. There is indication that the first decant line is likely completely filled with grout. The phase five decant line was to be abandoned the same way, but no documented confirmation is available.[17]

[17] Appendix 3 Reference 6

The first decant line outlet is visibly filled with concrete at the extreme downstream end but there is no proof of the entlre line being filled.

The team also discussed the possibility that drain 6 could be an old undocumented decant line because its construction is different lrom any other toe drain installed on the project. Further, it closely resembles the constmction style of the first documented decant line. Therefore, drain 6 could be an original decant line installed as part of the original impoundment built in 1954. Anecdotal information indicates Drain 6 may have been modified to allow interception of "groundwater spring" flows at the toe or foımdation area of the embankment after an original tower was abandoned. Evidence can be seen in a video of Drain 6 that shows a cross-drain opening at 342 feet within the pipe and the pipe continuing beyond this point. The team speculated tiiat this is possibly the "modified" groundwater spring drain entrance. The team concluded that drain 6 seems to be comected to a water source with increased pressure and flows greater than any other drain and deserves attention to leam more about the drain construction and its water source.

Monitoring and surveillance recommendations for the drains included a re-video of drain 6 to determine the extent of the pipe and to further explore the apparent cross drain inlet and determine if it is, in fact, an old decant line. Also, the team suggested the decant line inlets should be located. If found and the line can be unplugged, the decant lines should be videoed, features in the pipe should be located at measured distances and plans made to properly seal the inlet and grout fill within the entlre dovmstream pipeline.

6.7 SINKHOLE DEVELOPMENT

The possibility of sinkhole development on this project because of the high erodibility of the embankment material was not previously considered. Discussion of the project and construction techniques relative to the compaction of the embankment that lead to a high density and unsaturated material makes the embankment capable of sustaining an open "pipe" within the embankment that would otherwise be unlikely. Sinkhole development will be more closely monitored in the fiture.

Seasonal material transport has been observed during periods of high pore pressure and provides for the possibility that a void or voids may already exist within the embankment or may develop in the future. The team pointed out that the massive amount of material that has to be moved to create a sinkhole or an eventual breach of the dam reduces the chance of this being a rupid failure mode, however expansion of the void(s) over time until the void eventually reaches the surface has certainly been known to occur on many projects.

The Core Team found that the foundation gravels are not vulnerable to scour under high seepage gradients and the high capacity of the gravels likely assures that little to no saturution of the embankment occurs under normal operating conditions. Monitoring, surveillance and corrective action suggestions included the installation of added piezometer instrumentation and exploratory core drilling to definitively detemiine foundation composition.

The Core Team surmised that solutions associated to prevention of material transport and sinkhole development will be the installation of a filtered high capacity toe drain and downstream rock buttress system. The Core Team also suggested that reducing inflows could extend the drain life and decrease sinkhole development progression by the possible rerouting of stream flows aroumd the embankment.

6.8 EMBANKMENT FOUNDATION

A thorough and complete description of the foundation materials and the constraction activities involving the foundation was not found after a review of the available technical data. The only available information indicates a 6 foot depth of alluvial material on top of glacial outwash as the foundation below the KDID embankment. References to reports from 1971 were cited that may address these data gaps, but are not on file with the DNRC, the ovmer, or any of the project engineers that were available.

The Core Team felt that the gravel may have been intended to act as a transport medium to get water to the drains as this is a standard mine tailings dam technique; get water to the drains. Review of documents indicate that later phases of dam construction did involve stripping of the foundation but it is unclear, and is not documented to show whether or not this occurred during the initial constraction phase. The gravel and/or die foundation may very well be the pathway for seepage under the dam and, when the foundation material reaches capacity, the potentiometric water surface rises in piezometer P2.

The Core Team suggested that an attempt should be made to locate any past reports that reference foundation composition. If reports can not be found that corroborates foundation composition, geologic explorations should be made to more adequately understand the foumdation under the embankment dam as well as cores through the embankment to better understand constraction techniques utilized.

6.9 IMPOUNDMENT BY-PASS

The Core Team discussed rerouting Rainy Creek around the impoundment, as occurred during mining operations, as a corrective action on the project. By rerouting flows the reservoir size could be reduced or possibly removed depending on the design. The team determined that depending on the hydrologic design capacity of the diversion system, flood routing may still need to occur in the reservoir and therefore flows through the drains and spillways will still occur. Because the greatest failure concems with the impoumdment occur during flood conditions, a diversion of creek flows may not adequately address current risks with the embankment dam under these conditions. Therefore it is likely that rerouting creek flows will still result in necessary corrective actions on the dam itself. While a by-pass system may become the preferred altemative for creek routing in the future, the design must address any use of the impoundment for flood routing and include mitigation of the same possible failure modes associated with the continued use of the impoundment.

6.10 SURVEILLANCE

The Core Team recognized that there is measurement and monitoring equipment that provides a sufficient surveillance system on site but there is a need to have real time access to on site data. Real time data monitoring can be used to establish long term trends. Long term trends can be used to identify anomalies such as sudden or catastrophic changes in water surface, drain flows or outflows. Long term reliable monitoring data transmitted off site can be easily retrieved and safely stored. Current water level transducers on site can be wired to transmit real time water surface changes to a web site for real time water surface level monitoring.

The data collection discussed included geologic drilling to investigate the embankment and the foundation including core samples. By completing the bore hole with nested piezometers, transducers can be installed in the nested sections of the piezometers and, again, linked to real time data transmission. This data can be invaluable in monitoring and predicting drain flow and potentiometric water surface characteristics.

6.11 FUTURE PFMA REFERENCE COLLECTION

This report and its attachments are intended to be a reference document for future decisions and work projects performed on the site. It provides areas of identified weakness and susceptibility to adverse operating conditions and or failure. The recommendations listed herein are not requirements for work but rather suggestions to gain more information to make informed design decisions in the future.

Future data collection and monitoring on the site may identify more failure modes or the need to revisit and revise existing failure modes identified during the PFMA process. The team agrees that the documents created as a part of this process are intended to be working documents that are subject to change as explorations are completed, questions are answered or remedial work is performed on the site.

Future data may highlight failure modes that are not currentiy considered to be highly likely or carry a higher consequence to the environment or may change the stability and safety of the embankment dam. Future data may lessen the priority or eliminate potential failure modes.

This document should be kept current and up to date as more information is gathered and/or work is carried out that may change the vuhierabilities identified. It is recommended that the PFMA report be part of and appended to the Standard Operational Procedures for the KDID. This document should be reviewed annually or, at a minimum, as a part of the 5-year operational pennit renewal process. The report should be preserved in its original condition for future use and a correction copy completed at each review interval.

7.0 APPENDED REFERENCES

Reference **1.** Phase I Inspection Report – RAINY CREEK BASIN ZONOLITE TAILINGS DAM – September 1981. Morrison-Maierle Inc.

Reference 2. Rain on Snow PMF – Memo to Hardrock Mining Bureau - July 22, 1991. Shafer & Associates.

Reference **3.** Engineering Analysis of Flood Routing Altematives - 1991-1992. Shafer & Associates.

Reference **4.** Geotechnical Evaluation W.R. Grace Dam, Rainy Creek Montana – 1992. Harding Lawson and Associates.

Reference **5**, W.R. Grace Memorandum –Libby Impoundment Dam – December 1, 1981. From J.W. Wolter to R.M. Vining.

Reference **6.** Responses to W.R. Grace Closure Plan – First Review to Alan Stringer – May 22, 1992. Shafer & Associates.

Reference 7. Seizmic Hazard Assesment – Flower Creek Dam – DNRC Memo February 01, 2011. Montana DNRC.